13.

Morphological and Embryological Studies on Two Species of Marine Catfish, *Bagre marinus* and *Galeichthys felis.*

DANIEL MERRIMAN

Osborn Zoological Laboratory, Yale University.

(Plates I-V; Text-figures 1-9).

INTRODUCTION.

The material presented in this paper is based on a large number of preserved eggs, young, and adults, of the gaff-topsail catfish, *Bagre marinus*, and the silver or sea catfish, *Galeichthys*[1] *felis.* The collection of these specimens was made by Mr. M. B. Bishop of the Peabody Museum, Yale University, during 1938 and 1939, while working on a cooperative study of the tarpon at the field laboratory of the New York Aquarium at Palmetto Key, Florida. The entire collection was then put at the author's disposal through the generosity of Dr. C. M. Breder, Jr., Acting Director of the New York Aquarium, and Prof. A. E. Parr, Director of the Peabody Museum.

These two ariids occur commonly along the coasts of the southern Atlantic and Gulf states, but are comparatively rare north of Chesapeake Bay, although the northern limit of their range is Cape Cod (Breder, 1929). *Galeichthys felis* has been taken as far south as the Yucatan Peninsula (Hubbs, 1936), and *Bagre marinus* in Panama (Breder, *loc. cit.*).

The nomenclature of these two species has been discussed recently in papers by Hubbs (*loc. cit.*) and Lee (1937). Former names for *Galeichthys felis* (Linnaeus) include *Galeichthys milberti, Hexanematichthys felis, Arius milberti,* etc.; among those for *Bagre marinus* (Mitchell) are *Felichthys felis* and *marinus,* and *Ailurichthys* (emended to *Ælurichthys*) *felis* and *marinus.* Hubbs (*loc. cit.*) has also pointed out that Regan's (1907) *Galeichthys guentheri* is not separable from *G. felis.*

Both of these species are particularly interesting from a number of points of view. Thus it is well known that their eggs are among the largest found in the teleosts, averaging 14-19 mm. in diameter before fertilization and during the early stages of development. Furthermore, these catfish exhibit the phenomenon of oral gestation (Smith, 1907; Gudger, 1916 and 1918; and Lee, 1931 and 1937), the males picking up the eggs shortly after fertilization and carrying them in their highly modified mouths through the entire period of development up to the nearly complete absorption of the yolk-sac. Another interesting point about these species is the fact that both of them exhibit sexually dimorphic characters in the pelvic fins; the extraordinary hook-like protuberance on the adaxial surface of the pelvic fin in *Galeichthys felis* females has been described by Lee (*loc. cit.*) and Gowanloch (1933). The osteology of these forms is also of considerable

---

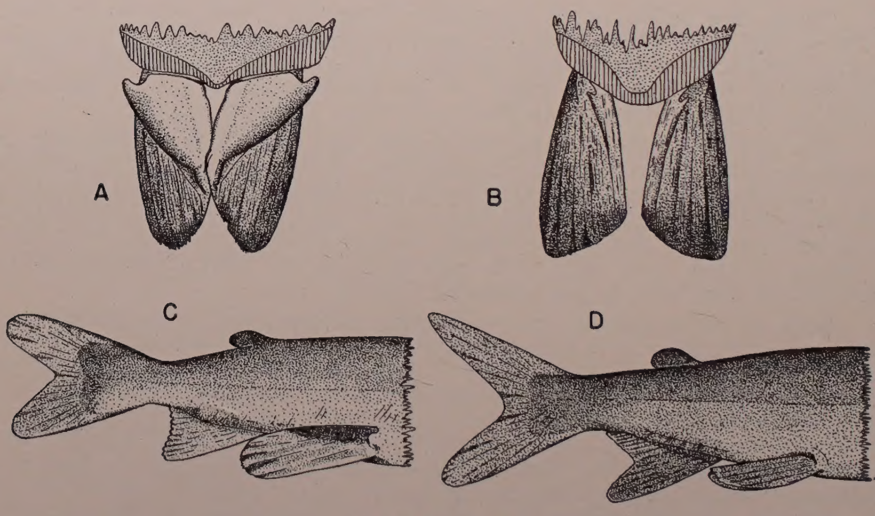
[1] The word Galeichthys comes from γαλ῀, weasel, and ιχθύς, fish (Jordan & Evermann, 1896).

importance because it illustrates the high degree of specialization so characteristic of the Nematognathi. Finally, the inner ears of *G. felis* and *B. marinus* are interesting because they show important structural modifications not found in other groups of fishes. Although most of these points have received some attention from a number of authors, many interesting details have been neglected. This paper takes up various morphological and embryological aspects of these two species, and treats them under the following headings: External Anatomy, Morphology of the Alimentary Tracts and the Feeding Habits, Osteology, Anatomy of the Inner Ear, and Embryology.

External Anatomy.

The external characters of *Galeichthys felis* and *Bagre marinus* which may be used in distinguishing these two species have been adequately described by many authors, among them Jordan & Evermann (1896), Smith (1907), and Breder (1929). A character which seems, however, to have been generally overlooked is the posterior margin of the anal fin, which in *B. marinus* has a prominent V-shaped indentation and in *G. felis* a comparatively straight border (Text-fig. 1, C and D). This does not show in the illustrations in Jordan & Evermann (1896) and Smith (1907), but Meek & Hildebrand (1923) describe the anal fin in members of the genus *Felichthys* as being "more or less emarginate." Another character which should be used with care is the description of the maxillary barbels as being flat and ribbon-like in *B. marinus,* as opposed to the condition in *G. felis* where the maxillary barbels are said to be "circular" in section. While it is true that these barbels are flatter and more ribbon-like in *B. marinus,* those of *G. felis* are distinctly flat over the greater part of their length, and only approach an oval condition in section at their extreme bases.

The modifications of the pelvic fins in adult female *Galeichthys felis* have been described and pictured in some detail by Lee (1937). The fleshy,



Text-figure 1.

A. The adaxial surface of the pelvic fins of a mature female *Galeichthys felis,* to show the fleshy protuberances which develop in the breeding season. **B.** The same view of the pelvic fins of a mature male *G. felis.* **C** and **D.** Lateral views of the posterior parts of the bodies of *G. felis* and *Bagre marinus* respectively.

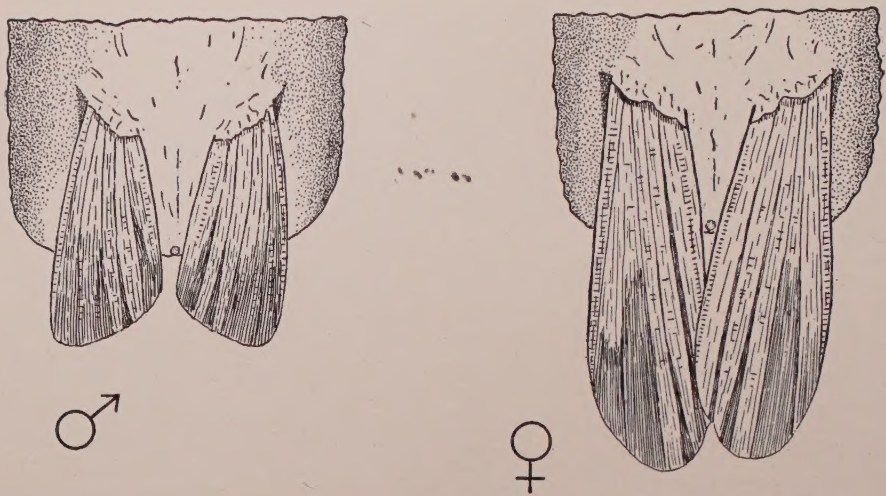
hook-like protuberances on the adaxial surface of the pelvic fins of a female nearing full maturity are shown in Text-fig. 1, A. As noted by Beeson (Lee, *loc. cit.*) this striking pelvic modification of the females becomes larger and more pronounced as the spawning season approaches, and then degenerates after spawning to a relatively inconspicuous affair. At the height of maturity these fleshy protuberances develop to such an extent that the greater part of each pelvic fin is forced into a more or less vertical plane. What is normally the adaxial (dorsal) surface is now turned outwards and is lateral in position, and the original abaxial (ventral) surface is turned inwards and is medial in position (Text-fig. 1, C). The pelvic fins of the females are thus forced into a trough-like structure at the time the eggs are extruded. There is some question as to the exact significance of these changes during the breeding season (Breder, 1935, and Hardenberg, 1935), and as to the uses which this modification might serve. In *Arius maculatus*, an East Indian form which also practices oral gestation, Hardenberg has described a similar development on the female's pelvic fins, and says, "This is a sexual character, which has something to do with spawning and mating. It is clear that the male is attached by these hooks and the fertilization of the eggs takes place perhaps inside the body of the female or more probably outside the body just at the moment when they leave the genital opening." Lee (*loc. cit.*) points out that, "In all probability this modification is widespread through the family, though not of universal occurrence, for Gudger failed to note the structure in *Bagre marinus* and Hubbs found it undeveloped in *Arius aqua-dulce* (as reported by Breder)." This author also has found no similar modification in *Bagre marinus* in his examination of numerous specimens, thus substantiating Gudger.

Lee (*loc. cit.*) says, "No such modification of the pelvic fin has been found in the male, although in egg-carrying males the fin shows a white, almost ridge-like area . . . , corresponding in position to the modification in gravid females. The significance of the ridge, if indeed it has any, is not understood; it is perhaps only a rudiment of a structure proper to the other sex." The figure accompanying this statement shows a vague area on the pelvic fin of a gestating male.

In the majority of male *Galeichthys felis* examined in the present work no modification was apparent, but in more than one-third of these male specimens there was a definite structure on the adaxial surface of the pelvic fins. Sometimes this modification was indistinct as indicated in Lee's figure, but at other times it was more conspicuous as shown in Text-fig. 1, B, where it is clearly seen to be a hook-like development not widely different from the condition found in immature and non-spawning females. Furthermore, this modification was found not to be confined to the gestating males.[2]

Lee (*loc. cit.*) has noted the fact that the pelvic fins of mature female *Galeichthys felis* are considerably larger, in proportion to the length of the fish, than in mature males of the same species. The author finds that this also holds true for the pelvic fins of *Bagre marinus*. This marked sexual dimorphism is shown in Text-fig. 2, where the pelvic fins of two gaff-topsail catfish of the same size are drawn from the abaxial surface. It is apparent that the fins of the male are not only much smaller than those of the female, but that they are also quite different in shape. Thus the greatest length of the male pelvics is on the outside of the fin—near its lateral margin. Also the posterior edge of the fin in males is relatively straight and slants obliquely inward (toward the medial margin, which has the shortest fin rays). By contrast, the female pelvic fins have their greatest length near the region of the middle fin rays. Furthermore, the posterior margins of the pelvics in females of this species are rounded in contour—

[2] The gonads of some of these male *Galeichthys felis* were sectioned to avoid any possibility of an error in sex determination—in other words, of their having been immature females.



Text-figure 2.

Abaxial views of the pelvic fins of male and female specimens of *Bagre marinus* of the same size. Note the typical sexually dimorphic characters.

not straight as in the males. This is obviously because the lateral and medial fin rays are shorter than those in the middle of the fin, thus making the posterior margin semi-circular in shape. Table 1 shows measurements on the pelvic fins of ten males and ten females of about the same size. The lengths of the fins were taken from the point marked by the junction of the lateral margin with the base, to the tip of the longest ray. The widths of the pelvics were measured from a point marked by the junction of the medial margin with the base, to the lateral margin in a line at right angles to the plane of the fin. The results of these measurements are shown at the bottom of Table 1, where it will be seen that the average lengths of the pelvic fins of males and females of the same standard lengths are 4.4 and 6.4 cm. respectively; the average widths are 1.2 and 1.4 cm. respectively.

TABLE 1.

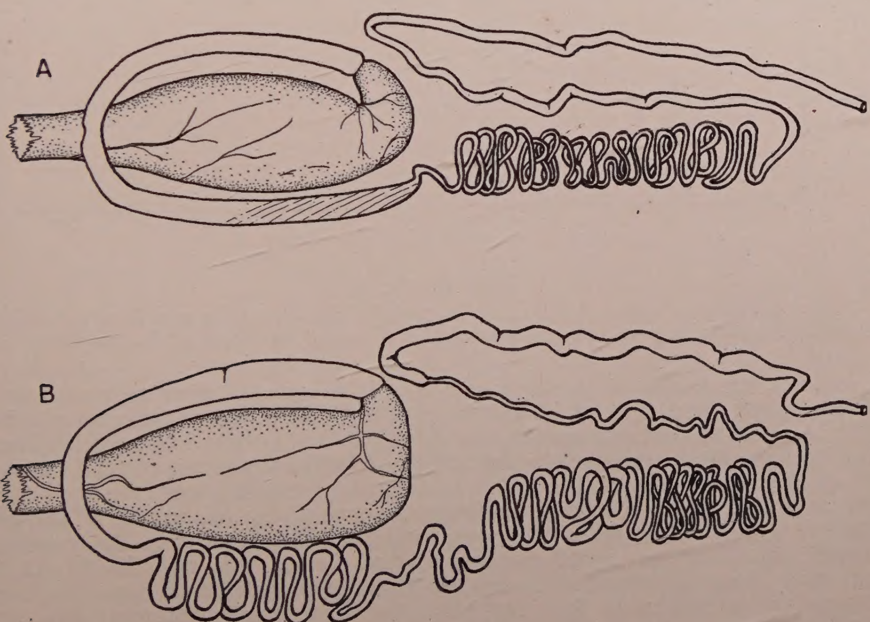
Comparative Lengths and Widths of Pelvic Fins of Male and Female *Bagre marinus*.

	Males			Females		
	Standard length of fish (cm.)	Length of fin (cm.)	Breadth of fin (cm.)	Standard length of fish (cm.)	Length of fin (cm.)	Breadth of fin (cm.)
	26.0	3.6	1.0	26.5	5.2	1.2
	26.5	3.7	1.1	27.0	5.4	1.2
	28.5	3.8	1.1	28.5	5.6	1.2
	32.0	4.5	1.1	28.5	5.8	1.2
	33.0	4.6	1.1	32.0	6.6	1.6
	33.0	4.4	1.2	34.5	7.1	1.3
	33.5	4.7	1.3	35.0	7.0	1.8
	33.5	5.0	1.4	35.5	6.2	1.3
	35.0	4.8	1.2	36.0	7.8	1.6
	39.0	5.3	1.7	37.0	7.2	1.6
Average	32.00 cm.	4.4 cm.	1.2 cm.	32.05 cm.	6.4 cm.	1.4 cm.

Morphology of the Alimentary Tracts and the Feeding Habits.

The general anatomy of the coelom and its organs is essentially the same in *Galeichthys felis* and *Bagre marinus,* and only minor differences exist. One of these differences is in the parietal peritoneum of the two species. In *Galeichthys felis* the peritoneal lining appears almost grayish, due to minute black pigment spots which are abundant over its otherwise white surface. These pigment spots are more numerous on the dorsal surface of the coelom than they are on the lateral and ventral walls of the body cavity. In *Bagre marinus,* however, there are no corresponding pigment spots, and the peritoneum is a clean, silvery white.

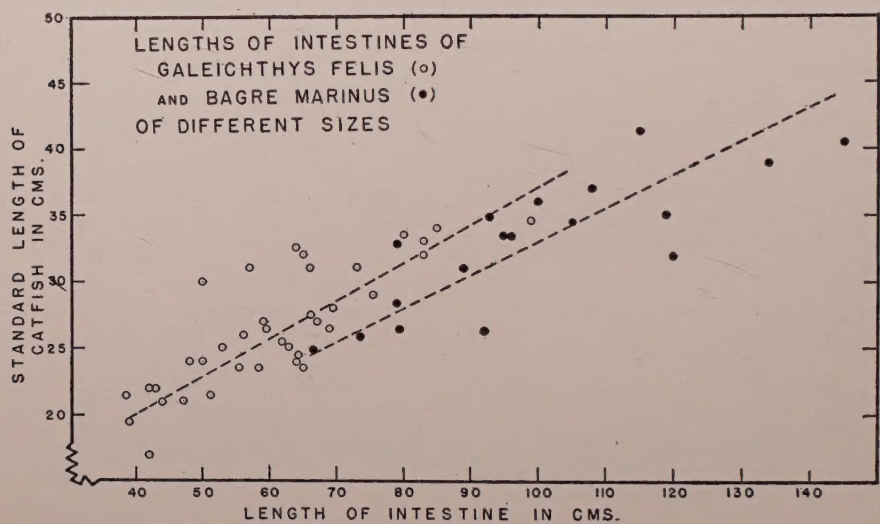
Among the more interesting of the differences between these two species are those found in the morphology of the alimentary tracts. It will be seen in Text-fig. 3 that the fundamental pattern of the gastro-intestinal tracts is the same in both species. Thus, in each type the intestine describes one and a quarter full loops. Yet there are distinct differences within that basic pattern, and these are constant for the species. Thus the stomach in *Galeichthys felis* (Text-fig. 3, A) is typically J-shaped. At its posterior end it makes a sharp bend anteriorly, decreasing in diameter as it does so, and ending in a characteristic constriction marking the pylorus. But the stomach in *Bagre marinus* (Text-fig. 3, B) turns only at right angles to the longitudinal axis at its posterior end and terminates abruptly with the constriction for the pylorus, which is somewhat less distinct in this species. Leaving the pylorus, in *Galeichthys felis* (Text-fig. 3, A), the intestine proceeds anteriorly, slightly lateral to the left side of the stomach. At the anterior end of the stomach it curves to the right and passes ventral to the junction of the oesophagus and the stomach. It then continues to curve sharply and passes posteriorly *as a straight tube* just lateral to the right side of the stomach. Only by the time that it reaches the posterior end of



Text-figure 3.

Diagrammatic sketches of the gastro-intestinal tracts of *Galeichthys felis* (A) and *Bagre marinus* (B)—ventral aspect.

the stomach does it suddenly become much smaller in diameter. Almost immediately it also takes on a highly convoluted form. These convolutions continue posteriorly nearly to the end of the coelom, where the intestine again turns anteriorly, simultaneously losing most of its convolutions. The intestine then runs to a point close to the pylorus, makes another sharp turn posteriorly and continues back to the anus without any section of it being highly convoluted. The intestinal pattern of *Bagre marinus* (Text-fig. 3, B), although fundamentally the same, differs strikingly in the point at which the convolutions first begin. Here they *start* just after the intestine curves under the junction of the oesophagus and stomach; in other words, the intestine does not continue as a straight tube so far posteriorly. Also there is no sudden decrease in the diameter of the intestine at the point where the convolutions first occur; instead the diameter decreases gradually. The intestine maintains its highly convoluted form to the posterior end of the coelom. It then curves abruptly and runs anteriorly as far as the level of the posterior end of the stomach, bends sharply on itself again and continues posteriorly to the anus; this latter part of the intestine has only minor convolutions.



Text-figure 4.

Graph of the lengths of the intestines of *Galeichthys felis* and *Bagre marinus* of different sizes, to show the proportionately longer intestine of *B. marinus*.

Since the intestine of *Bagre marinus* is convoluted over a greater part of its length than that of *Galeichthys felis*, it is a reasonable expectation that it would be proportionately longer. That this is true is shown by Text-fig. 4, where the lengths of the intestines of both species are plotted against the standard lengths of the fish. It is clearly evident that the length of the intestine in *Bagre marinus* is longer in proportion to the size of the fish than in *Galeichthys felis*. Thus in two individuals 30 cm. in standard length, the intestine would average 75 cm. in *G. felis* and 88 cm. in *B. marinus*. This difference is fairly constant, although it is apparent from the scatter of points on the graph that there is considerable variation and not infrequently an overlap between the two species. However, using Tippett's (1931) method for analysis of small samples, p is less than .001—in other words, the chances are less than 1 in 1,000 that the difference is not significant.

Stomach content analyses show that there is no essential difference in the diets of these two species. Both forms are completely omnivorous. Algae and various kinds of sea grasses are not infrequently eaten by them. Among the invertebrates, coelenterates (sea anemones), holothurians, gastropods, polychaets, and crustacea (isopods, and various decapods such as shrimps, spider crabs—*Libinia* sp., swimming crabs—*Callinectes sapidus* and *Ovalipes ocellatus*, etc.) are all eaten by these species. Teleost fishes also form a common item of their diet; among those which could be identified were: thread herring (*Opisthonema oglinum*), the slender sea robin (*Prionotus scitulus*), various poeciliids, haemulids, sparids and lutianids. There is no assurance, however, that these fishes were taken alive, and there is good reason to believe that many of them were eaten after being thrown back into the water by net fishermen. Both of these catfishes are scavengers and will apparently gather quickly in any place where refuse is thrown overboard. This is shown by the fact that large cycloid and ctenoid scales, which came from fishes that were much too large to be eaten by either of these species, were commonly found among the stomach contents, thus indicating that the catfishes had probably gathered near a boat or dock where fishes were being cleaned for market. The best example of their catholic tastes was found in the examination of the stomach of a single individual (*G. felis*); the contents included coffee-grounds, peas, and pieces of carrots, potatoes and meat.

In view of the fact that oral gestation is characteristic of the males of both species, it is of some interest to consider the feeding habits in relation to reproduction. Observations on preserved egg-carrying male *Galeichthys felis* and *Bagre marinus* are in agreement with those of Beeson (Lee, 1937). Aside from catfish eggs (see below), nothing was ever found in the stomachs of individuals practising oral gestation except an amorphous greenish or yellowish material; most of the time the stomachs were completely empty. Quite often, however, the egg-carrying males were found to have one or more eggs in their stomachs. As Lee has pointed out, these were probably swallowed "because of the confusion resulting when the fish are brought up in the trawl." This conclusion is supported by the observations of Lee and the present author—namely, that in most instances, the eggs showed little or no signs of digestion and were (in each individual's stomach) in the same stage of development as those in the mouth. However, in several specimens in the collection that forms the basis for this paper, eggs were discovered in the stomachs in an advanced state of digestion. A number of alternative explanations can be advanced to account for this. First, it is possible that the fish was frightened into swallowing the eggs at some time considerably previous to its eventual capture. Secondly, it is conceivable that the gastric juices had a chance to act on the eggs for some time, since the fish were not always preserved immediately after capture. Both of these possibilities seem unlikely, however; the second alternative is particularly so, since (as noted by Breder, 1935) the whole eggs should be rather resistant and the effects of digestion should be slight in such a short time, and since in the great majority of occasions when eggs were found in the stomach, they showed no effects of the digestive processes. Thirdly, it is possible that the egg-carrying males sometimes eat one or more of their eggs for nourishment during the time occupied by oral gestation. Since the period of incubation is apparently fairly long (see below), and any other means of obtaining food is impossible because the mouth is so full of eggs, this would not seem to be an unreasonable expectation. The possibility of gastric incubation has been fully discussed by Breder (*loc. cit.*), who cites Devincenzi's (1933) article in which "incubation gastrica" is described in the South American ariid, *Tachysurus barbus* (Lacépède). Breder places a different interpretation on Devincenzi's description most convincingly, despite the latter's interesting account of the high degree of vascularization of the stomach, and is inclined to believe that the eggs were swallowed from

fright at the time of capture. There is certainly no evidence for gastric incubation in *Galeichthys felis* and *Bagre marinus*. The fact that Lee (*loc. cit.*) and the present author have both found large catfish eggs in the stomachs of female *Galeichthys felis* would indicate that such eggs are not an entirely unacceptable item of diet. These eggs are not necessarily confined to this species, for in one instance the author found eggs that were almost certainly from *Bagre marinus*[3] in the stomach of a female *Galeichthys felis*.

Osteology.

The skulls of *Galeichthys felis* and *Bagre marinus* have received little attention other than that given them by Gudger (1916 and 1925), who pictured them both, but discussed their structure only briefly in relation to the size of the buccal cavity and the likeness of the ventral surface of each to a crucifix and halo[4] (Text-fig. 5, B and D), and by Regan (1911) in his paper on the classification of the order Ostariophysi.

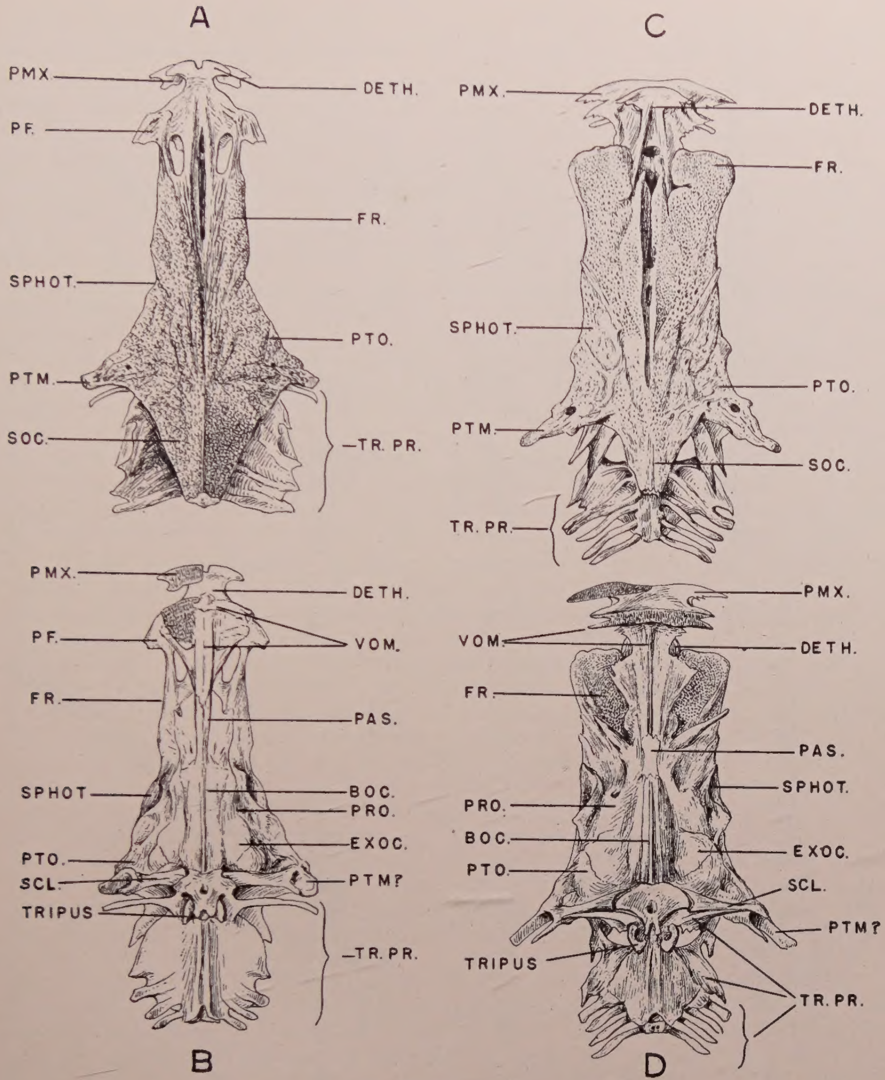
The present studies show that the high degree of specialization in the skull structure so characteristic of the Nematognathi (Gregory, 1933) is well exemplified by these two species. The bones of the roof of the skull are solidly fused together so as to form the typical cephalic shield (Text-fig. 5, A and C), to which the frontals, sphenotics, pterotics, post-temporals, and supraoccipitals contribute in both forms. Viewed from the dorsal surface, these bones are so well fused that it is extremely difficult to detect the sutures in adults. Here again, the fundamental patterns of the skull structure are much the same, and the main elements contributing to the skull are essentially similar in *Galeichthys felis* and *Bagre marinus*. Yet it is apparent that there are many distinct differences, not only in the shape of the individual bones and the whole cephalic shields, but also in the fontanelles and foramina. For instance, the frontals and supraoccipitals, especially the posterior processes of the latter, are strikingly different in their proportions. And it is clearly evident that the relations of the dermethmoids and premaxillaries are not precisely the same in both species (Text-fig. 5, A and C). The prefrontals are also somewhat different in the two forms, although they have been removed in Text-fig. 5, C and D. In *Bagre marinus* each one is characterized by the presence of a long, relatively thin spine which is directed posteriorly and lies ventral to the lateral edge of the frontal, eventually meeting a corresponding process of the frontal (see Text-fig. 5, D, for this process). In *Galeichthys felis* the *spine* is much more stout and unites with the lateral anterior portion of the frontal bone; it does not extend under the ventral surface of the lateral edge of the frontal.

In *Galeichthys felis* there is a single median fontanelle which is only partially divided about one-third of the way from its anterior end, and there are two large oval foramina just lateral to the anterior half of the fontanelle. The lateral edge of each foramen is formed by the fusion of the stout posterior spine of the prefrontal with the anterolateral part of the frontal.

---

[3] The eggs of these two species are not easily distinguishable (see below), but *Bagre marinus* spawns considerably in advance of *Galeichthys felis*, and in this instance the time of year this fish was captured and the condition of its own gonads, make it extremely unlikely that the eggs were not those of *B. marinus*.

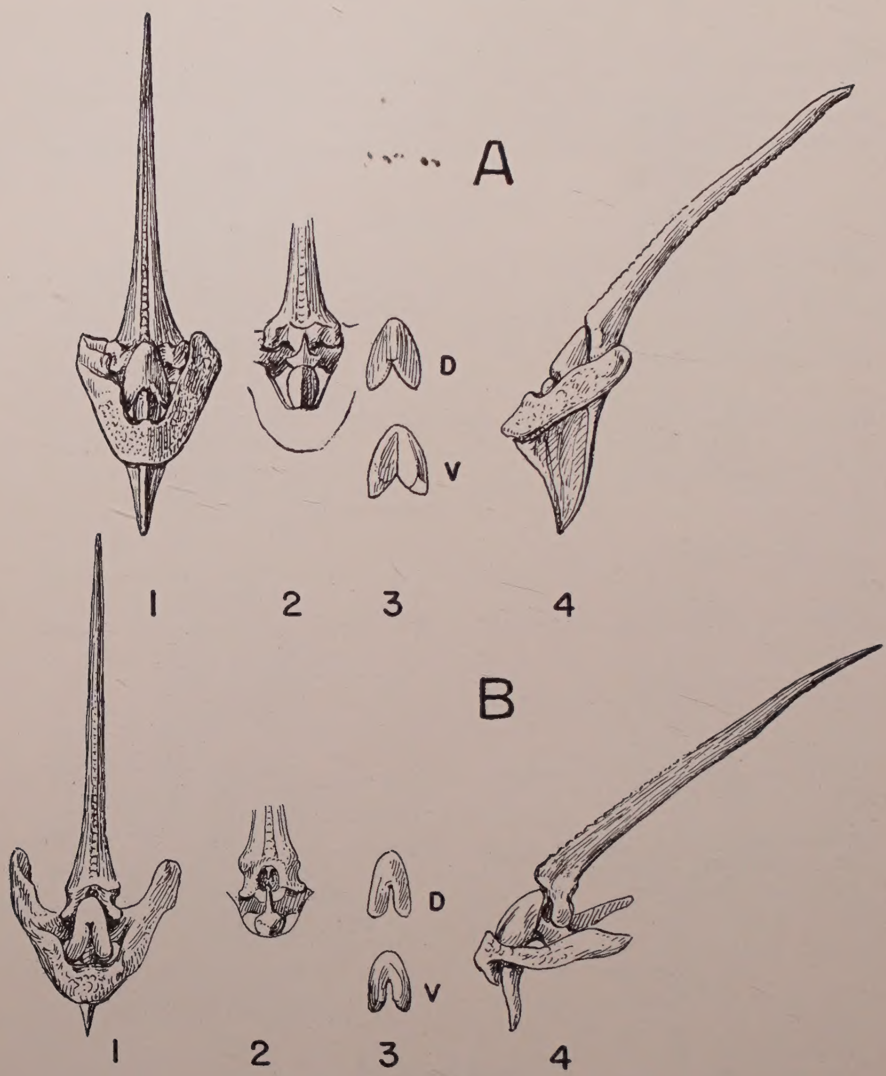
[4] Norman (1931) discusses this likeness to a crucifix and halo as follows, "Travellers in South America and the West Indies often return with tales of the so-called 'Crucifix-fish,' which is said to be held in great esteem and even veneration by the natives of these parts, who look upon it as a kind of fetish or charm against danger or sickness. These are nothing more than the prepared skeletons of certain Cat-fishes. . . . The skulls of many of these fishes exhibit on their lower surfaces a rough but readily recognizable resemblance to a crucifix, while the small bones known as the Weberian ossicles form a halo. The upper surface of the skull, with its rugose bones, has been described as resembling 'a hooded monk with outstretched arms,' or 'the breastplate of a Roman Soldier'; the dorsal spine is said to represent the spear; and the otoliths, which rattle when the skull is shaken, are the 'dice with which the soldiers cast lots for the garments of our Lord'!" Gregory (1933) in speaking of this resemblance of the under side of the skull to a crucifix, says, "No better example perhaps could be found of a class of fortuitous resemblances between wholly unrelated objects, which the late Professor Bashford Dean called 'Unnatural History Resemblances'."



Text-figure 5.

Dorsal and ventral views of the skulls of *Galeichthys felis* (**A** and **B**) and *Bagre marinus* (**C** and **D**).

These fontanelles are probably for the passage of sensory nerves to the snout and barbels. In *Bagre marinus* the median fontanelle is quite different. A small posterior section of it is separated from the main anterior part by a complete fusion of the bony elements in the mid-line (Text-fig. 5, C). The main fontanelle narrows in the middle of its passage forward, but widens into a V-shaped anterior end. Ahead of this terminal portion of the main fontanelle is a single, median, fairly large foramen. The anterior, posterior, and basal walls of this single median foramen in *Bagre marinus* have no perforations, and the only means of entrance into it are through distinct well-rounded apertures on its lateral walls. These apertures lead through canals in the prefrontals and vomer directly to the brain. It may be, therefore, that



Text-figure 6.

Different views of the nuchal shields of *Galeichthys felis* **(A)** and *Bagre marinus* **(B)**. **1.** Dorsal view of the shield and spine of the dorsal fin. **2.** Dorsal view of the articulation of the spine with the shield, the small bone shown separately in 3 having been removed. **3.** Dorsal and ventral views of the wedge-shaped bone lying just ahead of the spine of the dorsal fin. See text for description. **4.** Lateral view of the shield and its various elements.

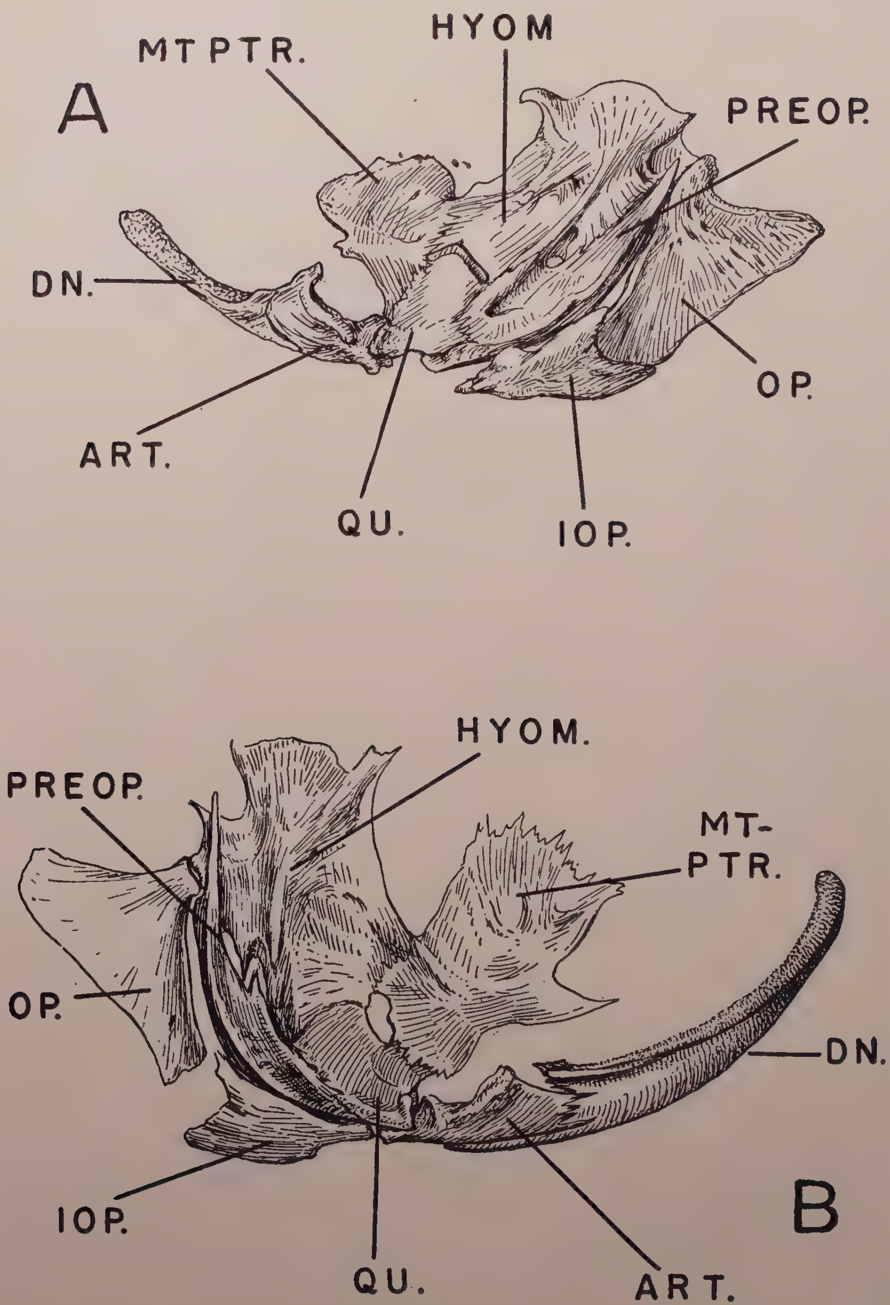
some of the nerves to the snout enter through the lateral walls and reach the surface of the skull via this anterior median foramen. The large, lateral, oval foramina which are so prominent in *Galeichthys felis* are covered over by the forward and lateral expansion of the frontals in *Bagre marinus*, and are only apparent when the skull is viewed from the anterior end. The skull of *Bagre marinus* is also characterized by a prominent foramen on each side

at the junction of the post-temporal and pterotic bones, while the corresponding foramina in *Galeichthys felis* are small and easily overlooked.

Gregory (1933) points out that "the jaws are peculiarly specialized in most siluroids in the reduction of the maxillae to small bones that support the barbels. *Diplomystes*, however, the most primitive catfish, has a well developed maxillary, expanded distally and toothed (Tate Regan, 1929, p. 316)." Both the species under consideration show the reduction of the maxillae clearly. And, as is further characteristic of the catfishes (Starks, 1926), the palatine is rod-like and separate from the pterygoid; however, it retains its attachment to the maxilla and is modified to help control the maxillary barbel. The bones supporting teeth in the roof of the mouth in both species are the premaxillaries and vomers, although as Hubbs (1936) has noted, there may be a wide variation in the vomerine dentition in *Galeichthys felis*. The vomerine and premaxillary teeth were all present in the specimen from which Text-fig. 5, B, was made, but the left half of each series was removed before the skull was drawn. The left premaxillary was removed before the drawing of the ventral surface of the skull of *Bagre marinus* was made (Text-fig. 5, D). It is apparent that the vomerine teeth in *Bagre marinus* form a bar of uniform width across the roof of the mouth. In *Galeichthys felis*, however, the vomerine teeth patches on each side tend to be triangular in shape, the apex of each triangle pointing posteriorly.

There are a number of other interesting points in the study of the ventral aspects of the skulls of these two species (Text-fig. 5, B and D). Among them are the distinct crescentic cavities in the sphenotic bones for the articulation of the curved dorsal edges of the hyomandibulars (Text-fig. 7, A and B). Also, the paired bullae, containing the unusually large utricular otoliths or lapilli (see below), are particularly prominent. Among the bones which contribute to these bullae are the exoccipitals, pterotics, and proötics. The post-temporal bones are of interest for several reasons. First, they are definitely annexed to the skull and form a part of the cephalic shield. Secondly, they apparently (see below) contribute to the formation of a pair of deep sockets for articulation of the sharp prong-like processes of the cleithra of the pectoral girdle (Text-fig. 8). These sockets differ somewhat in the two species, but have the same fundamental construction. Finally, the modifications at the base of the skull are interesting because they are so extreme, although they are essentially comparable to the condition in related forms. The Weberian ossicles (believed to be derived from the ribs and neural arches of the four anterior vertebrae) form a chain of bones on each side, connecting the air-bladder with the perilymph-filled spaces surrounding the inner ear. The tripus, in both species, as in some other Ostariophysi, consists of two parts, a crescentic posterior part, and an anterior section. The anterior vertebrae are highly specialized, possibly, as Gegory (1933) suggests, ". . . in order to support the massive skull." Regan (1929), describing these vertebrae in this group of fishes, says that the first vertebra forms a disc "rigidly united to the basioccipital and to the second, third, and fourth vertebrae, which are ankylosed to form a complex to which the fifth is rigidly attached and with the parapophyses ankylosed to the centra." The transverse processes in this region where the vertebrae are so highly modified are clearly different in *Galeichthys felis* and *Bagre marinus*, as is shown in Text-fig. 5, but here again the basic patterns are similar.

Just behind the posterior process of the supraoccipital, and in contact with its rear margin, in both species, lies a bony shield. This, according to Gregory (1933), is ". . . formed by the expansion and coalescence of the bony supports of the first three rays of the dorsal fin." The shields of both species are shown in Text-fig. 6. Together with the posterior process of the supraoccipital, each is known as a nuchal shield. These structures are much alike in the two forms under consideration, and differ only in the proportion and relative sizes of the elements making up the units. One of

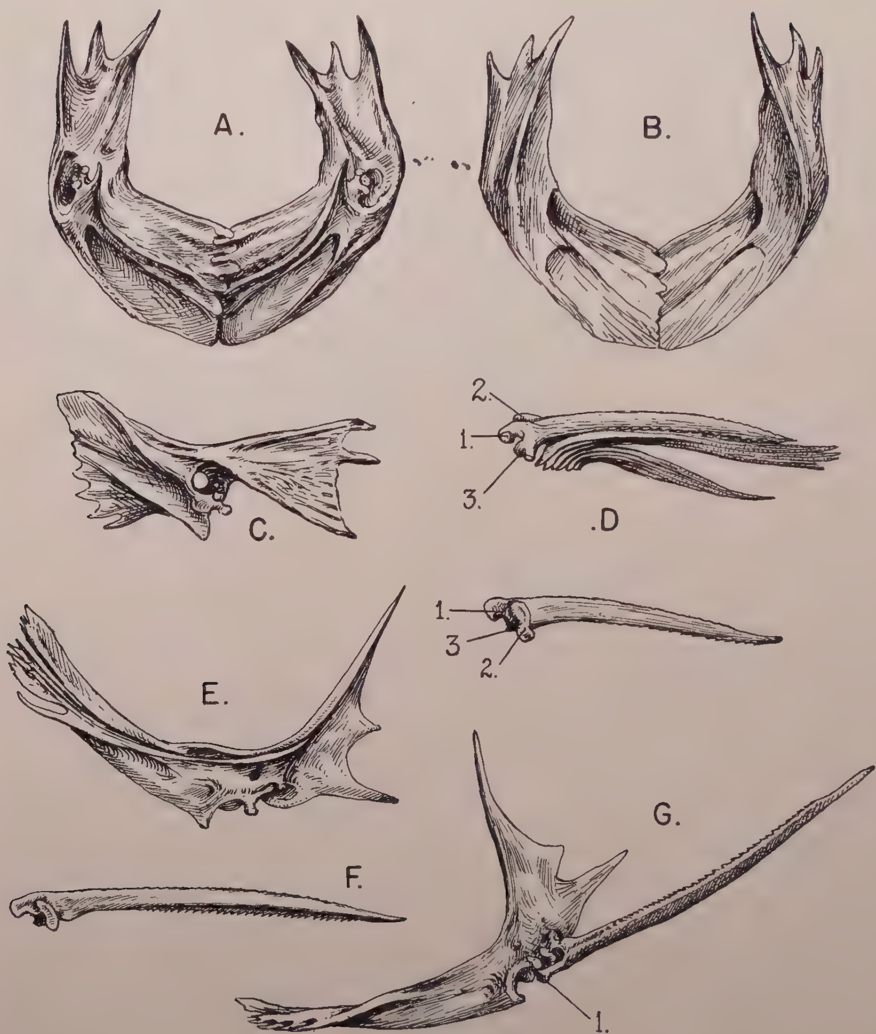


Text-figure 7.
Lateral views of the dentary and opercular series in *Galeichthys felis* (A) and *Bagre marinus* (B).

the more interesting of these elements is the V-shaped, wedge-like bone just anterior to the true spine of the dorsal fin. This is shown in Text-fig. 6, A1 and B1, in its natural position from the dorsal aspect; in Text-fig. 6, A3 and B3, removed from the rest of the elements forming the shield from its dorsal and ventral surfaces; and in Text-fig. 6, A4 and B4, in its normal position from the lateral aspect. This bone appears to be of significance in the articulation of the large spine of the dorsal fin only as a fundamental part of the locking mechanism which keeps the spine erect when it has been advanced to a vertical position. It possibly represents a rudimentary fin ray. Regan's (1911) account of the nuchal shield in siluroids describes this condition and the relations of the spines to the "interneurals" (basalia and radalia).

The lower jaw and opercular series in *Galeichthys felis* and *Bagre marinus* are shown in Text-fig. 7, A and B. Two points are of interest in this part of the skeleton. One is the complete absence of the subopercular bones in both of these forms. This disappearance of the subopercular (coincident with that of the parietals, opisthotic, and symplectic of the skull) is characteristic of the nematognath fishes (Gergory, 1933, and Regan, 1911). The opercle in these forms is in direct contact with the interopercle, and although Text-fig. 7, B, shows a gap between the two, this is simply due to a separation in the process of drying the skeleton, and the natural relationship is as shown in Text-fig. 7, A. The other point to be considered concerns the metapterygoid and the pterygoid bones. As described by Regan (1911) for the Ostariophysi, the metapterygoid has moved forward over the top of the quadrate, and it is relatively large and is connected suturally with the quadrate and hyomandibular. This condition is evident in Text-fig. 7, A and B. In the course of this movement it has taken over the normal position of the pterygoid. In many of the Ostariophysi the pterygoid has disappeared. Gregory (1933) says it has disappeared in all of this group except the Bagridae. This, however, is not actually so, for Regan (1911) has found it in some Ariidae. It is present in both *Galeichthys felis* and *Bagre marinus* (although not shown in Text-fig. 7), and lies dorsal to the metapterygoid and hyomandibular, and somewhat out of the normal relationship of this series. In these two forms the anterior part of the metapterygoid comes exceedingly close to the posterior edge of the palatine. The relationship of the metapterygoid with the surrounding bones is not unlike that shown for "*Amiurus*" by Kindred (1919, Fig. 15).

The pectoral girdles of both *Galeichthys felis* and *Bagre marinus* are shown from different aspects in Text-fig. 8. In both species the main element of the pectoral girdle is the cleithrum, the postcleithrum and the scapula apparently being completely lacking. What Regan (1911) calls the "hypocoracoids" (coracoids), "form an interlocking symphysis behind that of the cleithra." In these two species they are so solidly fused to the cleithra that it is extremely difficult to separate them or to see the sutures. In *Bagre marinus* they are slightly more easy to recognize as distinct entities than in *Galeichthys felis* where the fusion is particularly complete. In both species (Text-fig. 8), the serrated interlocking part of the pectoral symphysis is composed of the "hypocoracoids", and only the extreme anterior portion of the symphysis is formed by the cleithra. The problem of the supracleithrum is somewhat confusing. Regan (1911) describes it as follows for the siluroids: ". . . the supra-cleithrum . . . is typically forked, the upper limb usually rigidly attached to pterotic and epiotic, the lower to the basioccipital; . . . the distal part, 'stem', of the supra-cleithrum, beyond the fork, is deeply cleft to form a socket for the head of the cleithrum." And for the Ariidae he says, ". . . supra-cleithrum with stout lower limb united by suture with basioccipital." Text-fig. 5, B and D (SCL), show this relationship much as Regan has described it. Gregory (1933), however, labels the corresponding bone in an *Arius* sp. (Fig. 79) as the post-temporal, in which case the supra-



Text-figure 8.

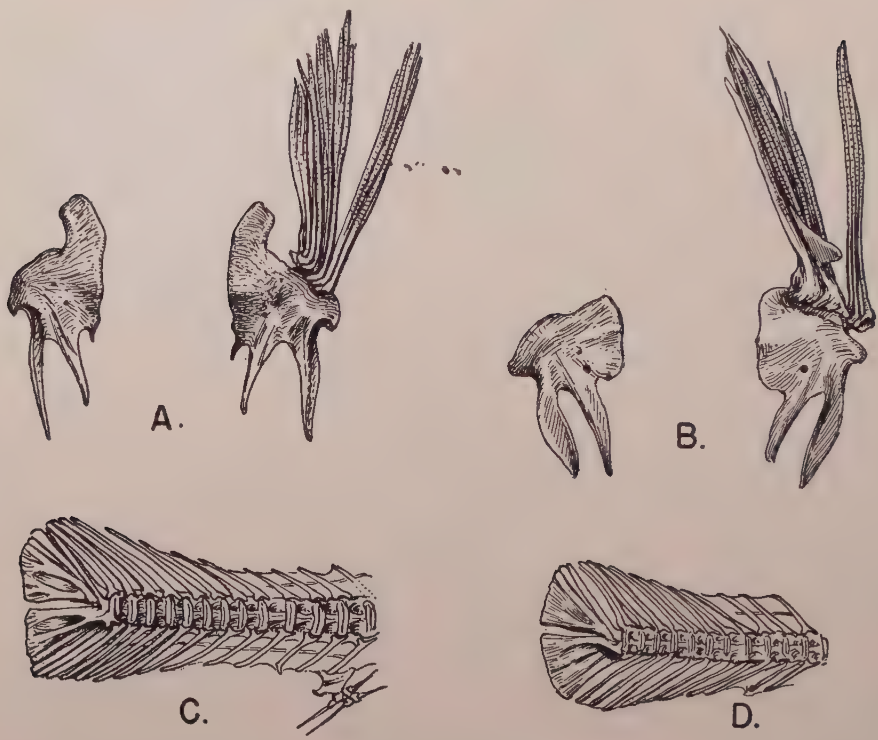
Various views of the pectoral girdle, its elements, and the serrated spine of the pectoral fin of *Galeichthys felis* **(A, B, C** and **D)** and of *Bagre marinus* **(E, F** and **G)**.

cleithrum must be lacking. It seems probable that Regan's interpretation is the more correct, but it also appears that the post-temporal contributes to the socket for the head of the cleithrum. However, because of the high degree of fusion in the bones of the skull in these species, it is difficult to tell in skeletons of adults where the original sutures lay. The dorsal parts of the pectoral girdles in both forms show three, prominent, prong-like processes. The most anterior of these cleithral prongs fit into the deep sockets shown on the base of the skulls in Text-fig. 5, B and D (see above). In Text-fig. 8, A and B, these articulating processes are the ones most medial in position, and in E and G they are the longest of the three prongs.

The articulation of the large serrated pectoral spine and its role as a sound-producing mechanism in both catfishes is of considerable interest. This subject has been discussed by Burkenroad (1931), who worked on *Galeichthys felis* ("*milberti*") and found that this fish has two methods of sound production. One is by means of a vibration of muscles in the dorsal body wall above the air-bladder, which "would appear to be an 'elastic spring' mechanism essentially similar to that described for other Siluroids by Sørensen (1884)." The other is by means of the highly complicated articulation of the pectoral spine in its socket (Text-fig. 8). There are two aspects of this articulation that deserve attention. One is a defensive locking mechanism when the spine is brought forward to a position at right angles to the longitudinal axis of the body. By means of this mechanism the spine is fixed in place and cannot be pushed back into its normal position unless the anterior (non-serrated) edge of the spine is slightly elevated and the base is simultanously rotated in a counter-clockwise manner ("counter-clockwise" when the right half of the pectoral girdle is viewed from the lateral aspect). This is due to a small nubbin of bone (Text-fig. 8, D and G, 1) which slips into a socket when the spine is advanced to the defensive position. When the proper muscles exert their action (note the depressions and foramina in the pectoral girdle for the passage of muscles in Text-fig. 8) the tongue-like ridge (Text-fig. 8, D, 2) of the pectoral spine fits into and rotates in a corresponding groove in the socket of the cleithrum. The other aspect of this articulation which deserves attention is the problem of just how and by what part of the base of the spine and its socket the stridulation is effected. This subject is intimately associated with the locking mechanism discussed above, and is reviewed by Burkenroad (1931) as follows:

"Sørensen, in connection with this phenomenon as observed by him in other siluroid species, states that the pectoral spine is fixed in position as a defensive weapon by the friction of an arched crest of its base against the adjacent 'scouring faces' of the articulation. He believes that the 'brake-like' action as the spine is moved to various defensive positions incidentally causes the sounds, which, however, he thinks may have a secondary function in frightening the assailant. Thilo (1896), with whom Sørensen (1896) disagrees, while not mentioning sound production, believes that the arched crest (designated by Sørensen as δ) is a portion of the diarthrosis of the joint. Thilo believes that the essential portion of the defensive locking mechanism is a prop-like projection (*Hemmfortsatz*) of the base of the spine; Sørensen, on the contrary, believes this peg, which he designates as β, to be a part of the diarthrosis. Dufossé (1874), has described the base of the pectoral spine of a siluroid both as a sound-producing and a locking mechanism. The structure and action of the pectoral spine of *Galeichthys milberti* seem to be similar to that of other siluroids described by previous workers."

Burkenroad does not think that (in *Galeichthys*) Sørensen's belief that sound is produced incidentally to the defensive fixation of the spine is correct. He believes, ". . . that the friction of the crest against the articulating surface . . . is adapted . . . to sound production." Thilo (*loc. cit.*) is undoubtedly correct in thinking that the arched crest (Text-fig. 8, D, 2) is part of the diarthrosis of the joint. Whether or not the arched crest is the only element that produces the sound by friction against the articulating surface is questionable in these two species. Burkenroad has pointed out that, "Along the lateral contact surface of the crest are a number of fine vertical striations which are thus probably to be considered as stridulatory ridges." These can be seen in Text-fig. 8, D, 2; there is no doubt that they possess the function ascribed to them and are of primary importance in this respect. Yet there is a third process (Text-fig. 8, D, 3) involved in the articulation of the pectoral spine which may possibly play a part in sound production. This process projects posteriorly, and when the spine is partially advanced its medial surface articulates with a small area on the coracoid. In prepared skeletons it is easy to manipulate the spine with only a slight pressure and produce a grating noise from the articulation



Text-figure 9.

A and **B**. Dorsal views of the elements of the pelvic girdles of *Bagre marinus* **(A)** and of *Galeichthys felis* **(B)**. **C** and **D**. Lateral views of the caudal fin skeleton of *B. marinus* **(C)** and of *G. felis* **(D)**.

described above. It seems possible, therefore, that this process is at times a sound-producing mechanism, but it certainly does not possess this function to the exclusion of that by the crest. It cannot function in this capacity simultaneously with the arched crest, since when the latter has the proper contact the former does not. It is at best no more than an incidental method of sound production.

The pelvic girdles of *Bagre marinus* and *Galeichthys felis* are shown from the dorsal aspect in Text-fig. 9, A and B. Sheldon (1937) has studied the osteology and myology[5] of the pelvic girdle of *Hexanematichthys* (*Galeichthys*) *felis,* and Text-fig. 9, B, is shown only for comparison with the pelvic girdle of *Bagre marinus.* The girdles of both species have much the same form. In each the basipterygia unite in the mid-line to form a symphysis, the whole structure being a bilaterally symmetrical unit, the "basal plate" (Sheldon). That of *Galeichthys felis* is slightly thicker and more substantial. Both species have two pairs of elongate anterior processes—an external and an internal pair. Each basipterygium has a single neural foramen in *Galeichthys felis,* while in *Bagre marinus* each has a

[5] Sheldon (1937) supports the view of Breder (1935) that the hook-like process on the adaxial surface of the pelvic fin in *Galeichthys* (see before) is used as a clasper in the spawning act, on the basis of his findings in the pelvic myology. He notes that various muscles (adductor superficialis, adductor profundus, and abductor profundus) have slips which are clearly differentiated and form almost independent muscles inserting on the most medial rays, which bear the clasper-like processes. This appears to him to be a clear indication of a powerful grasping function for these modified rays.

pair of somewhat less conspicuous foramina. The most prominent difference between the two pectoral girdles is the presence of a pair of broad flat posterior processes on the basipterygia of *Bagre marinus*. These are completely lacking in *Galeichthys felis*. They are situated on the medial part of the posterior margin of the basal plate, and Sheldon (*loc. cit.*) notes that in other nematognath forms they serve as a place of insertion for part of the retractor ischii muscles.

The skeletons of the caudal fins of both species are shown in Text-fig. 9, C and D, from which the large soft caudal fin rays as well as the small hypaxial and epaxial procurrent rays have been omitted. Here again the structures are fundamentally the same. In each the elements composing the hypural plate are similar. There are apparently six hypural bones, some of which, however, are well fused. These, of course, vary much in shape, but are not unusual in their distribution or size relationships. The urostyle is a prominent element of both caudal fins, extending almost to the posterior margin of the dorsal angle of the hypural plate. Above the urostyle there is but one dorsal caudal radial in each species. The proximal ends of the first three hypural bones (those most ventrally situated) contribute to the formation of a prominent ridge-like process in each species. This process is undoubtedly for muscle attachment, and is quite comparable to the "hypural spine" described by Merriman (1940) in *Roccus saxatilis*, and figured by Whitehouse (1910) for *Serranus cabrilla* and by Hollister (1937) in *Mugil curema*. The caudal skeletons of these catfish are, in general, characteristic of the less specialized homocercal tail; the long urostyle, and the number and disposition of the hypural bones are indicative of this low form of homocercy, as indicated by Whitehouse (*loc. cit.*).

Anatomy of the Inner Ear.

The anatomy of the inner ear of siluroid fishes has received little attention other than that given it by Neumayer (1908) and de Burlet (1929). De Burlet's paper contains a full account of the auditory organ of "*Amiurus*" (*Ameiurus*) *nebulosus* and other siluroids, and is by far the most extensive discussion of this subject. It does not, however, contain information on any of the Ariidae.

The otoliths of siluroids have been studied by Frost (1925), who has also recorded a utricular otolith resembling those of siluroids from the Upper Jurassic in England (1926). As Gregory (1933) notes, this "is another suggestion of the relative antiquity of the ostariophysial fishes." In North America the fossil siluroids are poorly represented. Among the Ariidae, Cope (1884 and 1891) described seven species belonging to the genus, *Rhineastes*, which he erected for them.[6] Lynn and Melland (1939) have described an interesting fossil catfish (*Felichthys stauroforus*) from the Maryland Miocene. Not only the skull, but also the structure of the otolith, clearly indicate that this individual is closely related to the two forms that are the subject of this paper.

The inner ears of *Galeichthys felis* and *Bagre marinus* are almost identical in structure. Each has a large rounded utriculus, with its utricular otolith or lapillus, above, and a smaller elongate sacculus, with its saccular otolith or sagitta, below. Each also has the small sac-like outgrowth from the sacculus, the lagena, the forerunner of the spirally twisted cochlea of higher vertebrates; these lagenae each have a characteristic otolith, the

[6] Lynn & Melland (1939) point out that, "The remains upon which these species are based are extremely fragmentary, consisting of small portions of skull plates, isolated fin-spines and otoliths. Nevertheless, they are sufficiently complete to indicate clearly that the genus belongs among the sea-catfishes so it has been assigned to the family Ariidae by Jordan (1923)." Hay (1929) lists five other species (besides Cope's seven) from North American deposits; these, however, are freshwater forms belonging to the family Ameiuridae.

asteriscus. These chambers with their otoliths and the semi-circular canals are shown in Plate I, A, B; the lapilli and asterisci removed from their respective chambers appear in Plate II, A, B, C, D.

The semi-circular canals are of course connected with the utriculus and are quite normal in relationships and distribution. There are the typical anterior and posterior vertical canals and the horizontal canal in each. The prominent ampullae are located in their usual positions and are clearly visible in Plate I, A, B. Due to the much enlarged utriculus, however, the semi-circular canals lie close to this upper chamber, and do not extend well above it as in other forms. Instead, the utriculus fills the whole space between the canals, and all three of the canals run close to and often touching the surface of the utriculus. The semi-circular canals are not solidly embedded in the bones of the skull, and only small portions of them pass through bone. It is also worth mentioning in passing that the utriculus is covered with a layer of highly pigmented tissue. This melanistic pigmentation is clearly visible in Plate I, A, B, although in A part of this tissue was removed before the photograph was made. The pigmentation is not confined to the utriculus and can be seen both on the ampullae and the semi-circular canals. The sacculus and lagena, by contrast, are unpigmented.

The sacculus and lagena are not unusual except in relation to the large size of the utriculus (see below). They are, however, solidly embedded in bone. The saccular otolith (sagitta) in both species is an elongate and highly brittle affair. Unlike the asteriscus or lapillus, the sagitta crumbles easily. It is irregularly circular in cross-section, narrowing at both ends and rounded at either extremity—in other words, it is roughly cigar-shaped. In adults it is 4-6 mm. in length. The otolith of the sac-like lagena, the asteriscus, from *Bagre marinus* is shown in Plate II, C, D, from the dorsal and ventral surfaces. In both forms it is a thin, disc-like affair, averaging 3-5 mm. in diameter in adults. The spiral appearance of its flat surface shown in Plate II, D, is characteristic of the two catfishes that form the subject of this paper. As can be seen in Plate I, B, the asteriscus lies directly above the sagitta, which runs in an antero-posterior direction, and its flat surfaces form dorsal and ventral sides.

In almost all fishes the sagitta is the largest otolith and the lapillus tends to be small and insignificant, although in some forms the sagitta is small and the asteriscus is relatively large. In *Galeichthys felis* and *Bagre marinus,* however, the utricular otolith or lapillus is much enlarged and dwarfs the sagitta and asteriscus by comparison. The lapilli of these adult catfishes may be as much as 15-16 mm. in diameter. As described by Frost (1925) their "shape is conchoidal and biconvex." Each has a prominent posterior process, and each has characteristic markings that are nearly identical in both forms (Plate II, A, B). Frost (*loc. cit.*) notes that in the Ariidae in general ". . . the lapillus is much larger, in comparison with the other otoliths, than in other Siluroids except the Plotosidæ." In conclusion he states, "In the Ostariophysi the saccular otolith, the sagitta, which is generally the principal otolith in other fishes, is attenuated and diminutive. In the Cyprinoids and *Diplomystes* the asteriscus is the largest otolith, in the Siluroids (except *Diplomystes* and a few South American species) the lapillus. It seems possible that the reduction of the sagitta may be related to the development of the Weberian mechanism, and that the great development of the lapillus or utricular otolith, in the Siluroids, may in muddy waters compensate for the decreased use of the eyes for maintaining equilibrium." This last statement appears to be somewhat debatable, but may well be a partial explanation of the relatively large size of the lapillus by comparison with that of the sagitta. Frost also points out that the interrelationships of the Siluroid families with each other and with the primitive characins are clarified considerably by studies on the otoliths.

EMBRYOLOGY.

Despite the fact that the eggs of *Galeichthys felis* and *Bagre marinus* are among the largest known in the teleost fishes, only a few authors have made any study of the embryology. This is partially because of the difficulty of getting a complete series of developmental stages, owing to the habit of the males in both forms of practicing oral gestation. Both Gudger (1916) and Lee (1937) experienced the greatest difficulty in keeping the eggs alive after removing them from the parent male's mouth. It therefore appears probable that the most feasible way to obtain a complete series is to collect the egg-carrying males in sufficient numbers until all the stages are filled. This necessitates a large collection since the eggs in a single male's mouth are usually all in the same stage of development.

The present studies are confined mainly to the eggs and larvae of *Galeichthys felis*, and are based entirely on preserved specimens. It is apparent from Gudger's (1916 and 1918) figures, however, that the eggs and larvae of *G. felis* are much like those of *B. marinus*. Comparing the small number of eggs of *B. marinus* in the present collection with those of *G. felis*, it is not easy to distinguish between the two forms in early stages. Gudger's (1918) measurements of the eggs of *B. marinus* would indicate that they average a little larger than the eggs of *G. felis*, but there is considerable overlap between the two forms since there is a wide variation in size in each type (see below). Many of the characteristics which serve as a means of distinguishing these catfishes when they become adults, however, are useful in separating the later egg stages of the two forms. Thus the barbels are sufficiently well developed some time before hatching to enable immediate identification, although the removal of the egg shell usually facilitates the necessary observations. The two barbels on the lower jaw of *Bagre marinus* and the four on that of *Galeichthys felis* are differentiated early in development. Also the much longer maxillary barbels and the filaments on the pectoral and dorsal spines in *B. marinus* are apparent well before hatching.

The study of the gonads of a large series of adult and immature specimens of *Galeichthys felis* and *Bagre marinus* varying in size from 17-44 cm. (standard length) has given some interesting information as to the time of spawning, the maturation of the ova, the age of maturity, etc. The individuals on which this study is based were collected in February, March and April, and June, July and August. It is evident from this collection that the main time of spawning for *G. felis* in 1938 on the west coast of Florida was June and July, while *B. marinus* spawned about a month earlier in this locality in that year. This information checks well with the conclusions of Lee (1937) on *Galeichthys felis*, which were based on observations over a number of years in the vicinity of Grand Isle, Louisiana.

The size of the eggs of *G. felis* just before spawning ranges from 12-19 mm. in diameter, the average being from 14-17 mm. Gudger's (1918 and 1919) measurements on the eggs of *B. marinus* show that the average size is 19-20 mm., and that the lower limits of size in this form are comparable to the average size of the eggs of *G. felis*. It should be mentioned, however, that Gudger's measurements were on unpreserved material, by contrast to those in the present study. But the limited number of measurements of the eggs of *B. marinus* which the present collection allowed, indicate that the eggs are usually somewhat larger than those of *G. felis*. The eggs of both forms vary in shape from a somewhat oval or elliptical to a perfectly spherical condition, the latter state, however, being much less common. The measurements given in this paper refer to the longest diameters in every instance. Just after spawning the largest eggs in the ovaries of these two forms average 2-4 mm. in diameter, although there are occasionally eggs up to 6 mm. in diameter. There are, of course, countless eggs of various

sizes below 2 mm. The larger eggs at this time are undoubtedly those which will be spawned the following season. It is of course impossible to obtain much information on the progressive increase in size of the developing eggs without material collected throughout the year. However, studies on a limited number of apparently maturing females of both forms taken in February, March and April, indicate that the increase in size of the eggs at this season is extraordinarily rapid, and that there is relatively little change in egg size from immediately after the time of spawning in the spring and early summer to January and February. In other words, the tremendous increase in bulk of the maturing eggs in both forms is mainly confined to the four or five months immediately preceding spawning; this increase in bulk is therefore not a progressive affair over an eleven or twelve months period, but is mainly concentrated in a much shorter space of time. Thus the largest maturing eggs from the gonads of *Bagre marinus* averaged from 5-8 mm. in diameter in February, about 14 mm. in diameter in March, and 18-19 mm. in diameter in samples taken in April. Similar samples of maturing eggs from the gonads of *Galeichthys felis* indicated that the increase in bulk of the eggs was equally rapid but did not start until a month or more later. In March the eggs were only 4 mm. or a little more in average diameter, but by April they had increased to 7 mm. in most instances, and in one individual the largest eggs were 12-14 mm. in diameter. The somewhat later period of rapid increase in bulk of the maturing eggs of *Galeichthys felis* is undoubtedly correlated with the correspondingly later time of spawning in this form.

The present collection was unfortunately rather limited in the numbers of immature individuals, so that it is impossible to draw many conclusions as to the size at which these two catfishes first become mature. Lee (1937) found one female *Galeichthys felis* only 12.6 cm. in standard length which was gravid. The present author has found a considerable number of female sea catfish up to and occasionally above 20 cm. (standard length) which were either immature or not spawning in that particular season, for their gonads had no eggs larger than 2-4 mm. in diameter immediately before the spawning season, at a time when mature fish possessed many eggs 14 cm. or more in diameter. These were not fish which had spawned in advance of the main lot, since their gonads were firm and full and did not have the typical flaccid, empty appearance characteristic of gonads that have just lost the mature eggs and show empty follicles. It therefore seems probable that there is a considerable variation in the size at which female *Galeichthys felis* first mature; this range is roughly from 12-20 cm., with the majority of individuals maturing for the first time near the upper end of the scale. No information was obtained as to the size at maturity of male *Galeichthys felis*, save from several individuals that were either immature or not spawning that season; these fish were 19 and 20 cm. in standard length respectively. It may therefore be that the males mature when slightly larger than the females. Males above 25 cm. were found to be mature. The collection did not contain any immature *Bagre marinus*, so it is impossible to draw any conclusions as to the length at maturity of this form. The smallest specimen was 26.5 cm. in standard length and was a mature female.

The problem of how many mature eggs are produced each season by the females of these two catfishes is of considerable interest in view of the large size of the eggs. In *Galeichthys felis* the number of mature eggs per gonad usually varies from 10-20, and the total number per fish 20-40. Occasionally a larger number of eggs were found, however; one individual collected just before the spawning season contained 53 mature eggs in its gonads, while another had 64 (39 in one gonad and 25 in the other). The average number of eggs produced each year by *Bagre marinus* is of the same order of magnitude. Evidence that all the mature eggs in one season are not extruded at one time in *Galeichthys felis* is forthcoming from the examina-

tion of gonads from individuals in the present collection. A number of females were found which possessed one gonad in which all the mature eggs had been released and in which empty follicles were plainly evident, but in which the other gonad had a few mature eggs and some empty follicles. Such an individual had certainly spawned once or more already, and in all probability would have spawned again that season and so have rid herself of the few remaining mature eggs, thus indicating that polygamy in this form is apparently not uncommon.

The number of eggs carried in the mouths of the orally gestating males has been treated by Gudger (1918) for *Bagre marinus* and Lee (1937) for *Galeichthys felis*. Gudger found this number to vary from 2 to 55, the average being from 15-30. The largest number of eggs in the mouth of a male *Galeichthys felis* recorded by Lee is 48. The average number is slightly less than that for *Bagre marinus*. In the same manner as indicated by Gudger for *Bagre marinus*, a single female *Galeichthys felis* can apparently produce more eggs than a single male can carry in his mouth, which is added evidence that polygamy is not uncommon among these forms.

The eggs in the mouth of any individual male are usually all in the same stage of development, but, as noted by Lee (1937), there are exceptions. Sometimes there may be several infertile eggs among the developing ones, and rarely one or two eggs that are in a much earlier stage of development than the main lot. Undoubtedly the infertile eggs are picked up with the fertile ones by the male at times. It may also be that if a male does not acquire his full complement of eggs the first time, he will attempt to pick up additional eggs later on. On the other hand, several eggs in an earlier stage than the majority in a male's mouth may simply be cases of retarded development, as suggested by Lee.

As mentioned before, the young remain in the parent male's mouth long after hatching, in many instances up to the time when the yolk sac is completely absorbed. Gudger (1918) believes the entire incubatory period to be 60 to 70 days in *Bagre marinus* near Beaufort, N. C. Evidence from the present collection indicates that the time occupied by oral gestation is somewhat shorter for both *Galeichthys felis* and *Bagre marinus* on the west coast of Florida, and that 6 to 8 weeks is the period there; this estimate, however, is based on an inadequate amount of material (see below). Gudger is convinced that the young *Bagre marinus* actually feed while still in the mouth of the parent male, ". . . filtering out of the respired sea-water, by means of their closely set gill rakers, minute crustacea to satisfy their hunger." Proof that this supposition is correct not only for *Bagre marinus* but also for *Galeichthys felis* is provided by the dissection of individuals in a late stage of development but still in the parent males' mouths. Stomach content analyses showed that in almost every instance these small fish had been feeding heavily. There is some possibility, of course, that the small fish feed outside the parent male's mouth and subsequently return to it or are picked up again by the male.

The developmental stages of *Galeichthys felis* are shown in Plate II, 1-6, and Plate III. Plate II, 1, shows the whole egg in which the developing embryo is at the earliest stage represented in the entire collection. The egg shell has not been removed (as it has in the succeeding photographs in this figure), and it is possible to see the distinct space between it and the yolk and developing embryo. This perivitelline space is apparently formed at or shortly after the time of fertilization, when the chorion moves out from the yolk which it so closely surrounds before fertilization. Plate II, 2, shows the same stage with the egg shell removed, and the developing embryo is clearly visible on the surface of the yolk. A photograph of a whole mount of this embryo dissected away from the yolk is shown in Plate III, 1. It is obvious that at this stage the eye and lens are clearly differentiated, mesodermal segmentation has progressed a long way, the

somites being evident over the greater part of the entire length of the fish, neuromeres are distinctly visible, the pectoral limb buds are apparent, and the otoliths have formed. The frontal and sagittal sections of embryos of this stage shown in Plate IV, 1, 2, 3, also illustrate these points. It is characteristic of the yolk at this stage to show an irregular trough-shaped indentation of considerable size in the vicinity of the embryo. The embryo usually lies at one end of this indentation, the posterior part of its body being in it, while the anterior end extends out onto the smooth surface of the yolk. This is probably the groove into which the embryo fits so closely at subsequent stages.

It is of some interest to consider why no earlier stages were present in the entire collection despite the large number of eggs which were examined. Gudger (1916) failed to obtain any of the segmentation stages in his studies of *Bagre marinus*, but got a complete series "from invagination to the free swimming young in which the walls of the belly have closed over the diminished yolk sac and have coalesced into a raphe on the median line." In *Galeichthys felis* the absence of any early stages may possibly be accounted for by the following statement by Smith (1907): "Spawning occurs in the summer, the large eggs being first deposited in a sandy depression and subsequently taken into the mouth of one of the parents. . . ." Others have made similar observations (Gudger, 1918), which, if reliable, would account for the lack of early stages in the mouth of any orally gestating male.

The next stage of development in *Galeichthys felis* is shown in its normal relation to the yolk in Plate II, 3, as a whole mount of the embryo dissected away from the yolk in Plate III, 2, and in sagittal section in Plate IV, 4, 5. By this time there has been a considerable advance over the previous stage. The eyes have become particularly prominent, the pectoral limb buds have enlarged considerably, and the "coiling" of the body so characteristic of the later stages has started with the twisting of the caudal end of the embryo to a position where it is at right angles to the longitudinal axis of the body. This coiling in a more advanced state is apparent in Plate II, 4, 5, and Plate III, 3. Here it will be seen that the posterior half of the body has twisted to such an extent that the caudal fin at least touches the head and more usually overlaps it completely. This coiling is neither universally sinistral or dextral; however, it tends to be counter-clockwise in the majority of the specimens examined. It will be noticed that the pigmentation of the dorsal surface of the body becomes increasingly prominent as this coiling stage is more fully developed. The barbels, which serve as a means of distinguishing these two catfishes (see before), are also clearly evident by this time. Furthermore, the prominent utricular otoliths have attained a large size at this stage and the hypural plate has undergone considerable development (see Plate III, 3). Sagittal sections through the anterior part of the body at the coiling stage are shown in Plate V. The parasagittal section in Plate V, 1, shows the well-developed eye with its retina and lens, the characteristic and perfectly normal gill arches, and the large space in the posterior part of the neurocranium that is the site of the more prominent part of the inner ear—namely, the semicircular canals, utriculus, and lapillus. The nearly median sagittal section at the same stage (Plate V, 2) indicates, by comparison with sagittal sections of the previous stage, that the main steps in organogenesis have been accomplished during this phase of development. Thus the swim-bladder, with its distinct partitions, the oesophagus and gut with its rugose lining, the beginnings of the convolutions of the gastro-intestinal tract, the kidney, etc., are now clearly evident.

The developing embryo apparently remains in the coiled stage up to the time of hatching. Shortly after hatching the yolk sac is still large, but the larvae are well-developed and most of the fundamental differences

between *Bagre marinus* and *Galeichthys felis* are readily apparent—e.g., see the photograph of the newly hatched *G. felis* in Plate II, 6. The yolk sac is now gradually absorbed, and, as mentioned before, the small fish are regularly found in the parent males' mouths up to and even some time after the complete disappearance of the yolk sac.

Finally some information on the rate of development of *Galeichthys felis* is provided by the following data. The eggs in the earliest stage taken (Plate II, 2, and Plate III, 1) were found in the mouths of males commonly in late July, and in one instance in mid-August in 1938. Those in the succeeding stages of development (Plate II, 3, and Plate III, 2) were taken most frequently in late July and early August, although these too have been collected in mid-August or slightly later. Embryos in the late coiling stage were taken in greatest numbers in mid-August, although it was not uncommon to find individuals which had hatched and even those in which the yolk sac had been completely absorbed by this time. Unfortunately the collection of material stopped shortly after the middle of August, so that it was impossible to draw any conclusions as to how much later oral gestation is carried on. The largest individual taken from the mouth of a parent male at this time was 49.5 mm. in standard length, and many larvae averaging about 40 mm. were collected at that date. The above information indicates that in 1938 on the west coast of Florida, hatching occurred in about a month, and that the larvae were retained in the parents' mouths from 2-4 weeks thereafter.

Summary.

1. The material presented in this paper is based on a large number of preserved eggs, young, and adults, of the gaff-topsail catfish, *Bagre marinus*, and the silver or sea catfish, *Galeichthys felis*, which were collected in the vicinity of Palmetto Key, Florida. Various morphological and embryological aspects of these two catfishes are discussed under the following headings:

External Anatomy.

2. A distinguishing character which seems to have been generally overlooked, is the posterior margin of the anal fin, which in *B. marinus* has a prominent V-shaped indentation and in *G. felis* a comparatively straight border. The cross-sectional shape of the maxillary barbels of the two species is not as clearly diagnostic as a distinguishing character as it has been described to be.

3. The pelvic fins of mature (or nearly mature) female *G. felis* have extraordinary, fleshy, hook-like protuberances on the adaxial surfaces; the males not infrequently exhibit a similar, though far less well developed, structure. Neither male nor female *B. marinus* possess corresponding modifications of the pelvics.

4. The pelvic fins of mature females of both forms are considerably larger, in proportion to the length of the fish, than in mature males of the same species. The sexually dimorphic character of the pelvic fins of *B. marinus* is apparent both as to size and shape.

Morphology of the Alimentary Tracts and the Feeding Habits.

5. The parietal peritoneum in *G. felis* appears almost grayish, due to minute black pigment spots which are abundant over its otherwise white surface, and which are more numerous on the dorsal surface of the coelom than on the lateral and ventral walls of the body cavity. The peritoneum of *B. marinus* lacks any melanistic pigmentation, and is a clean, silvery white.

6. The fundamental pattern of the gastro-intestinal tracts is the same in both species. Yet there are minor differences between the two which are constant for each form. Among these is the fact that the length of the intestine in *B. marinus* is longer in proportion to the size of the fish than in *G. felis.*

7. Stomach content analyses show that there is no significant difference in the diets of these two species. Both forms are completely omnivorous. There is certainly no evidence for gastric incubation in *G. felis* and *B. marinus,* although the eggs of these catfish are apparently not an entirely unacceptable item of diet at times.

Osteology.

8. The present studies show that the high degree of specialization in the skull structure so characteristic of the Nematognathi is well exemplified by these two species. Thus the bones of the skull are solidly fused together in both forms so as to form the typical cephalic shield. The fundamental patterns of the skull structure are essentially similar, yet there are many distinct differences, not only in the shape of the individual bones and the whole cephalic shields, but also in the fontanelles and foramina; these are described in some detail.

9. A nuchal shield lies just behind the posterior process of the supraoccipital, and in contact with its rear margin, in both species. These structures are much alike in the two forms, but show characteristic differences.

10. Studies of the lower jaw and opercular series show several interesting specializations. Among these is the complete disappearance of the subopercular (coincident with that of the parietals, opisthotic, and symplectic of the skull), and the relation of the metapterygoid and pterygoid bones.

11. The main elements of the pectoral girdles are the cleithra and coracoids, and the articulation of these girdles in both forms is accomplished by prominent cleithral prongs which fit into deep sockets on the base of the skull. The articulations of the serrated pectoral spines with the girdles are highly complex, involving defensive locking-mechanisms and sound-production.

12. The pelvic girdles in these catfish are much alike, although that of *B. marinus* is characterized by a pair of broad flat posterior processes on the basipterygia.

13. The caudal skeletons are characteristic of the less specialized homocercal tail, as indicated by the long urostyle and the number and disposition of the hypural bones.

Anatomy of the Inner Ear.

14. The inner ears of *G. felis* and *B. marinus* are almost identical in structure. Each has a large rounded utriculus, with its utricular otolith or lapillus, above, and a smaller elongate sacculus, with its saccular otolith or sagitta, below. Each also has a small sac-like outgrowth from the sacculus, the lagena, the forerunner of the spirally twisted cochlea of higher vertebrates; these lagenae each have a characteristic otolith, the asteriscus.

15. In almost all fishes the sagitta is the largest otolith and the lapillus tends to be small and insignificant, although in some forms the sagitta is small and the asteriscus is relatively large. In *G. felis* and *B. marinus,* however, the utricular otolith or lapillus is much enlarged and dwarfs the sagitta and asteriscus by comparison. The lapilli of these adult catfishes may be as much as 15-16 mm. in diameter.

Embryology.

16. The eggs of *B. marinus* and *G. felis* are much alike, although those of *B. marinus* are, on the average, slightly larger. Many of the characters which serve as a means of distinguishing these catfish as adults are useful in separating the later egg stages of the two forms—e.g., the barbels.

17. Studies of the gonads of these catfishes indicate that the main time of spawning for *G. felis* in 1938 on the west coast of Florida was June and July, while *B. marinus* spawned about a month earlier in this locality in that year.

18. Observations on the gonads of a limited number of apparently maturing females of both forms taken in February, March and April, indicate that the increase in size of the eggs at this season is extraordinarily rapid, and that there is relatively little change in egg size from immediately after the time of spawning in the spring and early summer to January and February. In other words, the tremendous increase in bulk of the maturing eggs in both forms is mainly confined to the four or five months immediately preceding spawning.

19. There is probably considerable variation in the size at which female *G. felis* first mature; this range is roughly from 12-20 cm., with the majority of individuals maturing for the first time near the upper end of the scale.

20. The total number of mature eggs produced by the females of these two catfish is usually from 20-40 per individual, although there are some instances where the numbers are smaller or larger than these limits.

21. The numbers of eggs carried in the mouths of the orally gestating males vary greatly in both forms, the average being 10-30. A single female can apparently produce more eggs than a single male can carry in his mouth, which, in the light of other evidence, indicates that polygamy is not uncommon among these forms.

22. The eggs in the mouth of any individual male are usually all in the same stage of development, although there are exceptions. The young remain in the parent male's mouth long after hatching, in many instances up to the time when the yolk sac is completely absorbed. The incubatory period on the west coast of Florida is probably about 6-8 weeks long. The young taken from the mouths of parent males were often found to have been feeding independently, as evidenced by the presence of small crustacea in their stomachs.

23. The earliest stage of development in this collection is represented by a number of specimens in which the eye and lens are clearly differentiated, mesodermal segmentation has progressed a long way, the somites being evident over the greater part of the entire length of the fish, neuromeres are distinctly visible, the pectoral limb buds are apparent, and the otoliths have formed. A possible explanation of the lack of earlier stages in the mouths of orally gestating individuals may be that the eggs are first deposited in a sandy depression and subsequently taken into the mouth of the parent male.

24. The later stages show the characteristic "coiling" of the body, the time at which the main steps in organogenesis occur, and various external and internal developmental features of interest. All available stages have been studied as whole mounts, and in sagittal and frontal sections.

25. Studies on the rate of development indicate that in 1938 on the west coast of Florida, hatching occurred in about a month, and that the larvae were retained in the parents' mouths from 2-4 weeks thereafter.

Bibliography.[7]

Breder, C. M., Jr.

1929. Field book of marine fishes of the Atlantic Coast from Labrador to Texas. G. P. Putnam's Sons, New York and London, The Knickerbocker Press: 1-332.

1935. The reproductive habits of the common catfish, *Ameiurus nebulosus* (Le Sueur), with a discussion of their significance in ontogeny and phylogeny. *Zoologica*, 19 (3): 143-185.

Burkenroad, M. D.

1931. Notes on the sound-producing marine fishes of Louisiana. *Copeia*, 1: 20-28.

Cope, E. D.

1884. The Vertebrata of the Tertiary formations of the West. Book I. *Rept. U. S. Geol. Surv. of the Terrs.*, 3: 1-1009.

1891. On Vertebrata from the Tertiary and Cretaceous rocks of the Northwest Territory. I. The species from the Oligocene or Lower Miocene beds of the Cypress Hills. *Geol. Surv. Canada, Contr. to Canadian Pal.*, 3: 1-25.

de Burlet, H. M.

1929. Anatomisches zur Hörfähigkeit der Siluroiden. *Zeitschr. f. Anat. u. Entwick.*, 89: 11-27.

*Devincenzi, G. J.

1933. La perpetuacion de la especie en los Peces Sudamericanos. *An. Mus. Hist. Nat. Montevideo*, 2a Ser. 4 (2): 1-28.

*Dufossé, M.

1874. Recherches sur les sons expresifs que font entendre les poissons d'Europe. *Ann. Sci. Nat., Zool.* (5), 9 (5) and 20 (3).

Frost, G. A.

1925. A comparative study of the otoliths of the Neopterygian fishes (continued) (II B. Ostariophysi). *Ann. and Mag. of Nat. Hist.* (9), 16: 433-446.

1926. Otoliths of fishes from the Jurassic of Buckinghamshire and Dorset. *Ann. and Mag. of Nat. Hist.* (9), 18: 81-85.

Gowanloch, J. W.

1933. Fishes and fishing in Louisiana. *Bull. 23, State of La. Dept. of Conservation*, New Orleans: 1-638.

Gregory, W. K.

1933. Fish skulls, a study of the evolution of natural mechanisms. *Trans. Amer. Philos. Soc.*, N. S., 23: 75-481.

Gudger, E. W.

1916. The gaff-topsail (*Felichthys felis*), a sea catfish that carries its eggs in its mouth. *Zoologica*, 2 (5): 123-156.

1918. Oral gestation in the gaff-topsail catfish, *Felichthys felis*. *Papers from the Dept. of Mar. Biol. of the Carnegie Instit. of Wash.*, 12 (Pub. No. 252): 25-52.

1919. The ovary of *Felichthys felis*, the gaff-topsail catfish; its structure and function. *Papers from the Dept. of Mar. Biol. of the Carnegie Instit. of Wash.*, 13 (Pub. No. 281): 111-128.

1925. The crucifix in the catfish skull. *Nat. Hist.*, 25 (4): 371-380.

*Hardenberg, J. D. F.

1935. Miscellaneous notes on Indian fishes. IV. On the propagation of *Arius maculatus* (Thunb.). *Natwurk. Tijdsch. Nederl.-Ind.*, 95: 54-57.

[7] A * indicates that the original paper has not been read by this author, and that the information is derived from the work of others who have cited this material in their own publication.

HAY, O. P.

1929. Second bibliography and catalogue of the fossil vertebrates of North America. *Carnegie Instit. of Wash.*, Pub. No. 390, 1: 1-916.

HOLLISTER, G.

1937. Caudal skeleton of Bermuda shallow water fishes. II. Order Percomorphi, Suborder Percesoces: Atherinidae, Mugilidae, Sphyraenidae. *Zoologica*, 22 (3): 265-279.

HUBBS, C. L.

1936. Fishes of the Yucatan Peninsula. *Publ. Carn. Instit. Wash.*, Pub. No. 457: 157-287.

JORDAN, D. S.

1923. A classification of fishes, including families and genera as far as known. *Stan. Univ. Publ., Biol. Sci.*, 3: 79-243.

JORDAN, D. S. & EVERMANN, B. W.

1896. The fishes of North and Middle America. *Bull. U. S. Nat. Mus.*, 47 (Pt. 1): 1-1240.

KINDRED, J. E.

1919. The skull of Amiurus. *Illinois Biol. Monogr.*, 5 (1): 1-120.

LEE, G.

1931. Oral gestation in the marine six-whiskered catfish, *Galeichthys felis. Anat. Rec.*, 51 (1), Suppl.: 60.

1937. Oral gestation in the marine catfish, *Galeichthys felis. Copeia*, 1: 49-56.

LYNN, W. G. & MELLAND, A. M.

1939. A fossil catfish (*Felichthys stauroforus*) from the Maryland Miocene. *Jour. of the Wash. Acad. of Sciences*, 29 (1): 14-20.

MEEK, S. E. & HILDEBRAND, S. F.

1923. The marine fishes of Panama. *Field Museum of Natural Hist., Zool. Ser.*, 15 (Pub. No. 215) (Pt. 1): 1-330.

MERRIMAN, D.

1940. The osteology of the striped bass (*Roccus saxatilis*). *Ann. and Mag. of Nat. Hist.* (11), 5 (25): 55-64.

NEUMAYER, L.

1908. Zur vergleichenden Anatomie des Gehirns und des Cavum Cranii der Siluroiden. *Anat. Anz.*, 32: 273-277.

NORMAN, J. R.

1931. A history of fishes. Ernest Benn, Ltd., London: 1-463.

REGAN, C. T.

1906-1908. Pisces. *Biologia Centrali-Americana*: 1-203.

1911. The classification of the Teleostean fishes of the order Ostariophysi.—2. Siluroidea. *Ann. and Mag. of Nat. Hist.* (8), 8: 553-577.

1929. Fishes. *Encycl. Brit.* (14), 9: 305-328.

SHELDON. F. F.

1937. Osteology, myology, and probable evolution of the Nematognath pelvic girdle. *Ann. N. Y. Acad. Sci.*, 37 (1): 1-96.

SMITH, H. M.

1907. The fishes of North Carolina. *N. Car. Geol. and Econ. Surv.*, 2: 1-449.

SØRENSEN, W.

*1884. Om Lydorganer hos Fiske. Copenhagen. *Dissertation.*

1896. Some remarks on Dr. Thilo's memoir on "Die Umbildungen an den Gliedmassen der Fische." *Morph. Jahrb.*, 25: 170-189.

STARKS, E. C.
1926. Bones of the ethmoid region of the fish skull. *Stanford Univ. Publ., Biol. Sci.*, 4 (3): 139-388.

THILO, O.
1896. Die Umbildungen an den Gliedmassen der Fische. *Morph. Jahrb.*, 24: 287-355.

TIPPETT, L. H. C.
1931. The methods of statistics. Williams and Norgate, Ltd., London: 1-222.

WHITEHOUSE, R. H.
1910. The caudal fin of the Teleostomi. *Proc. Zool. Soc. of London*: 590-629.

EXPLANATION OF THE PLATES.

PLATE I.

A. Dorso-lateral view of the utriculus and semi-circular canals of *Bagre marinus*. The sacculus has been removed.

B. Side view of the inner ear of *Galeichthys felis*. Note the large size of the utriculus.

PLATE II.

Otoliths from *Galeichthys felis* and *Bagre marinus*.

A. Views of the two sides of the lapillus from *B. marinus*.

B. The same from *G. felis*.

C and **D.** Dorsal and ventral aspects of the asteriscus of *B. marinus*.

1-6. Various developmental stages of the eggs and larvae of *Galeichthys felis*.

PLATE III.

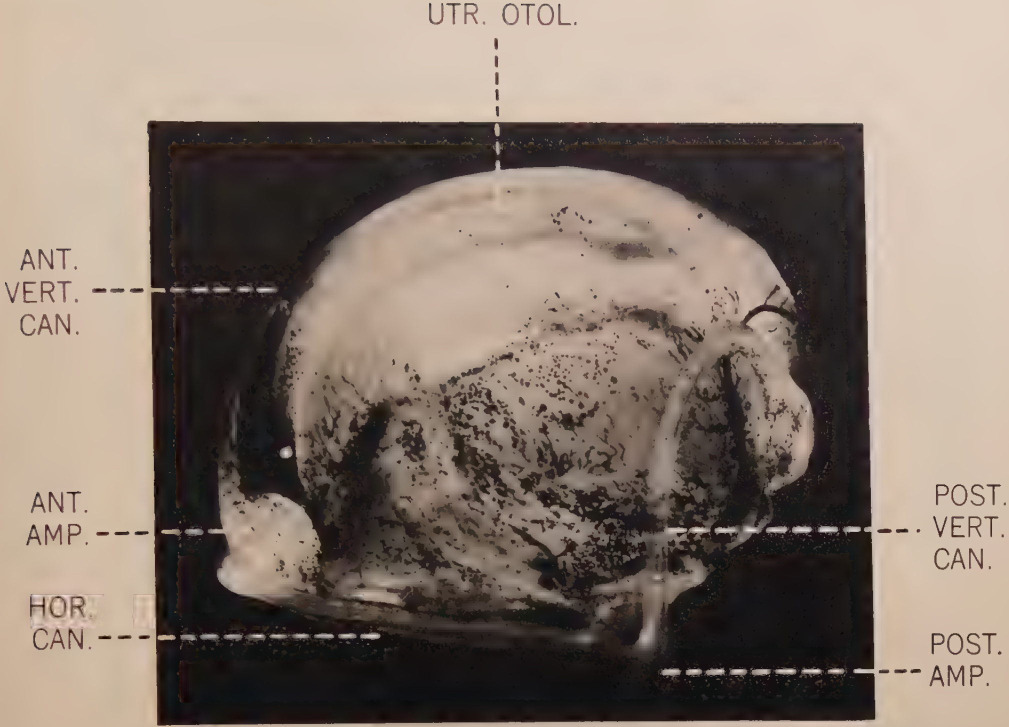
1-3. Whole mounts of the embryos of *Galeichthys felis* in different stages of development.

PLATE IV.

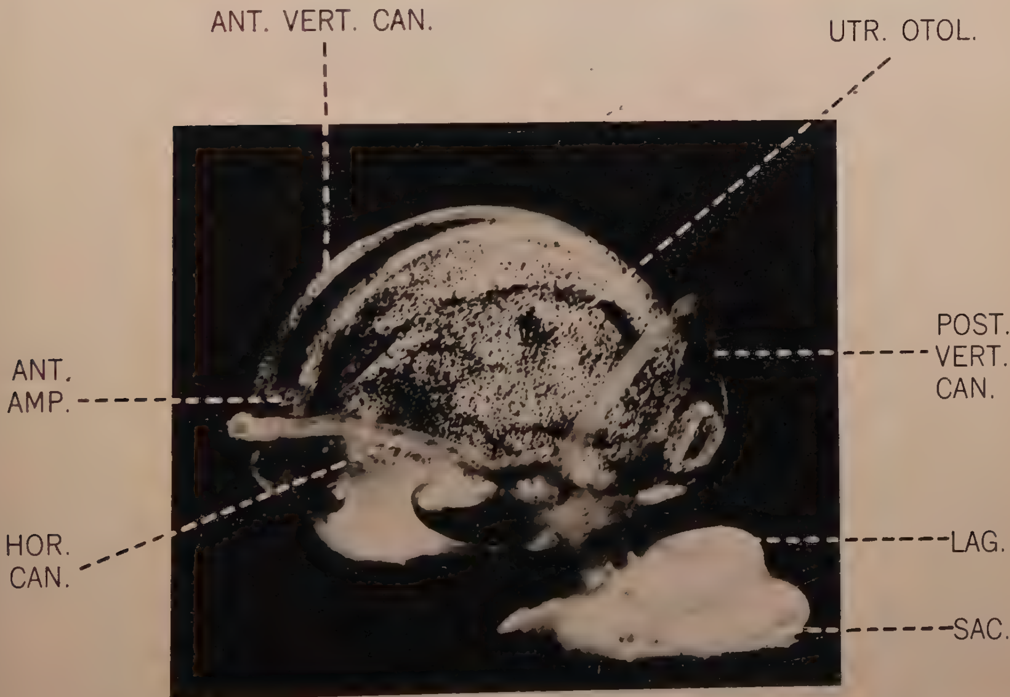
1-5. Sagittal and frontal sections of *Galeichthys felis* embryos in various stages of development. See text for description.

PLATE V.

1 and **2.** Sagittal sections through the anterior part of the body of *Galeichthys felis* in the "coiling" stage of development.

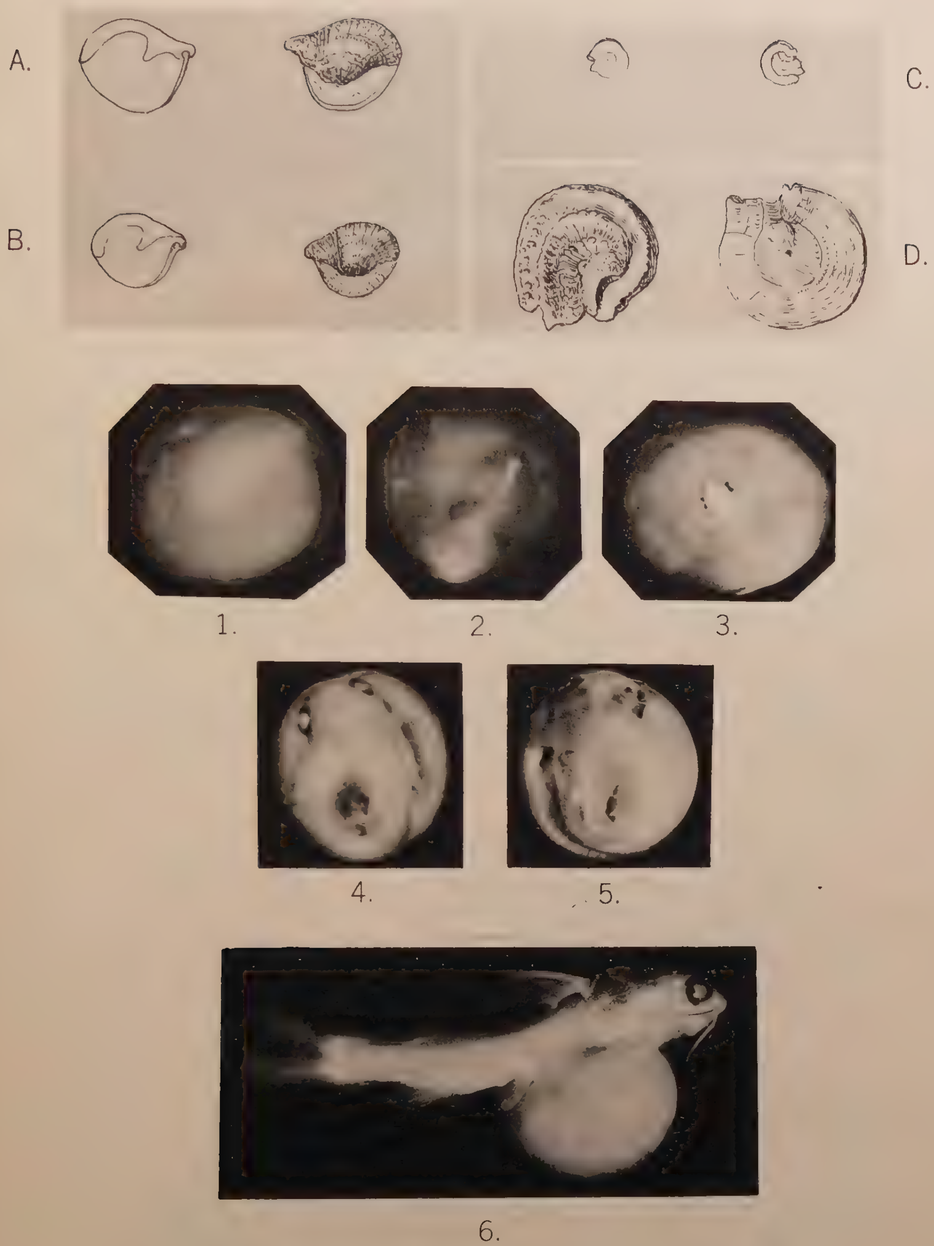


A.

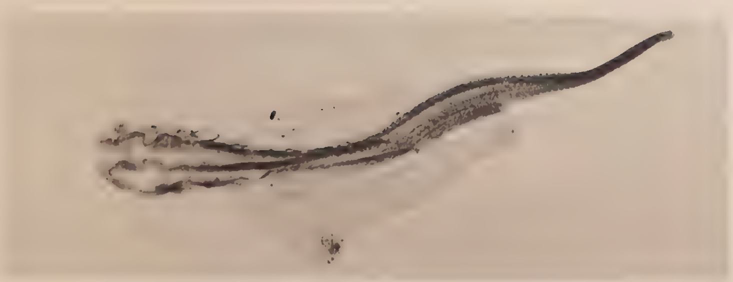


B.

MORPHOLOGICAL AND EMBRYOLOGICAL STUDIES ON TWO SPECIES OF MARINE CATFISH, BAGRE MARINUS AND GALEICHTHYS FELIS.

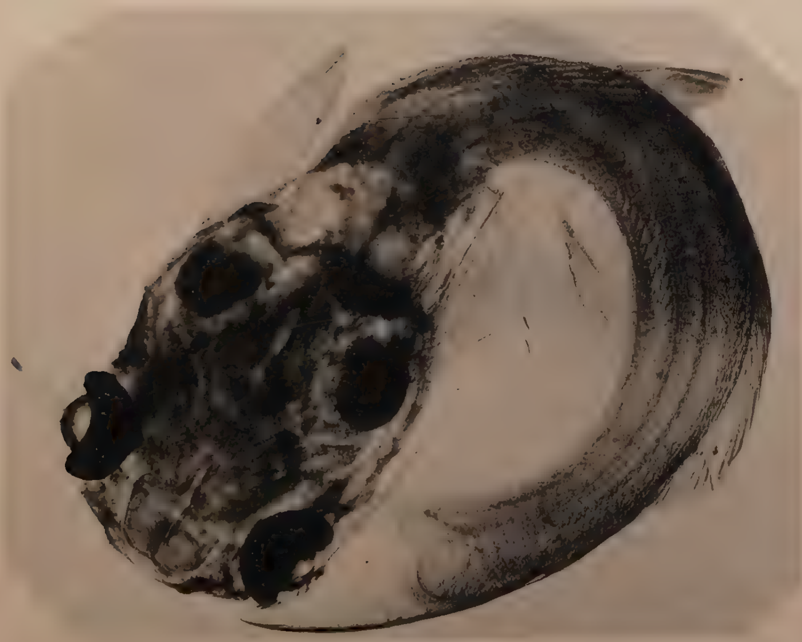


MORPHOLOGICAL AND EMBRYOLOGICAL STUDIES ON TWO SPECIES OF MARINE CATFISH, BAGRE MARINUS AND GALEICHTHYS FELIS.



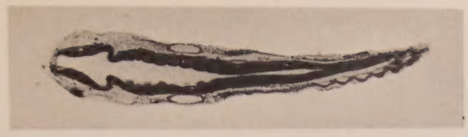
1.

2.

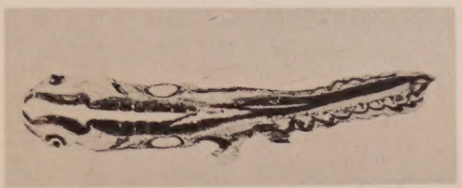


3.

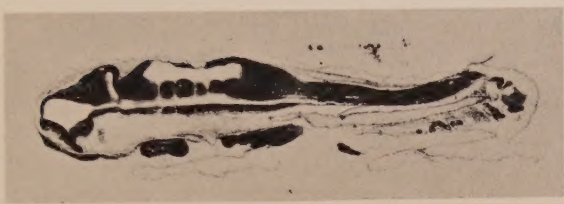
MORPHOLOGICAL AND EMBRYOLOGICAL STUDIES ON TWO SPECIES OF MARINE CATFISH, BAGRE MARINUS AND GALEICHTHYS FELIS.



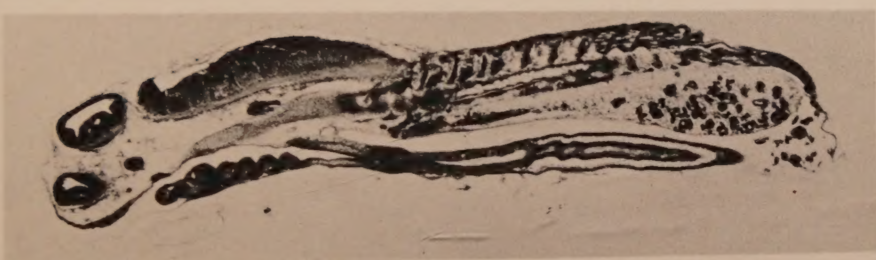
1.



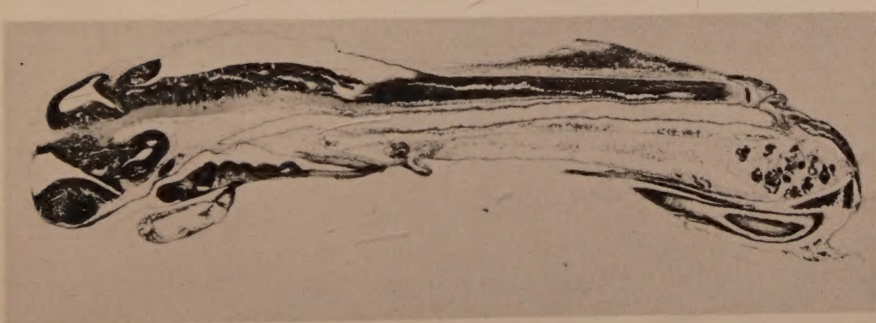
2.



3.

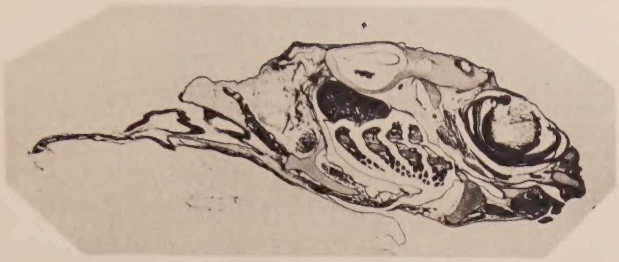


4.



5.

MORPHOLOGICAL AND EMBRYOLOGICAL STUDIES ON TWO SPECIES OF MARINE CATFISH, BAGRE MARINUS AND GALEICHTHYS FELIS.



1.

2.

MORPHOLOGICAL AND EMBRYOLOGICAL STUDIES ON TWO SPECIES OF MARINE CATFISH, BAGRE MARINUS AND GALEICHTHYS FELIS.